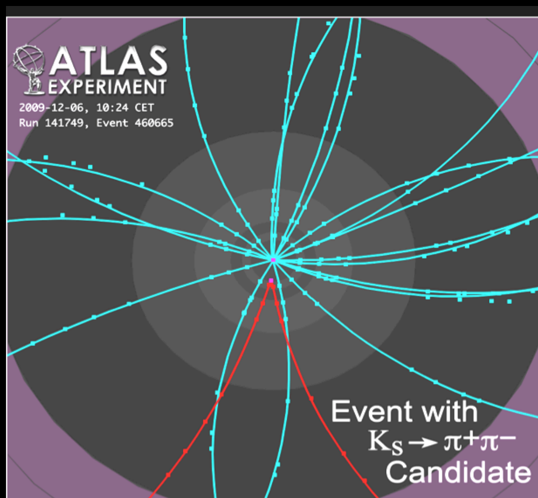
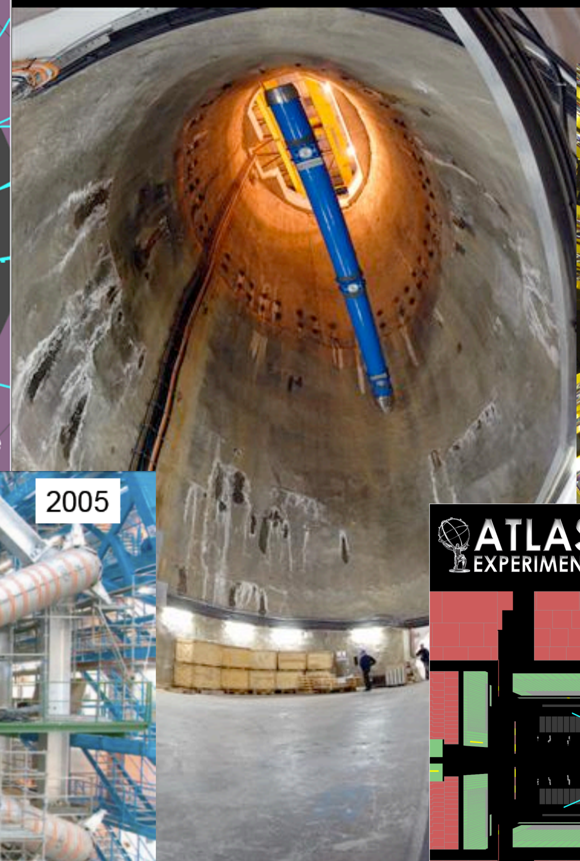
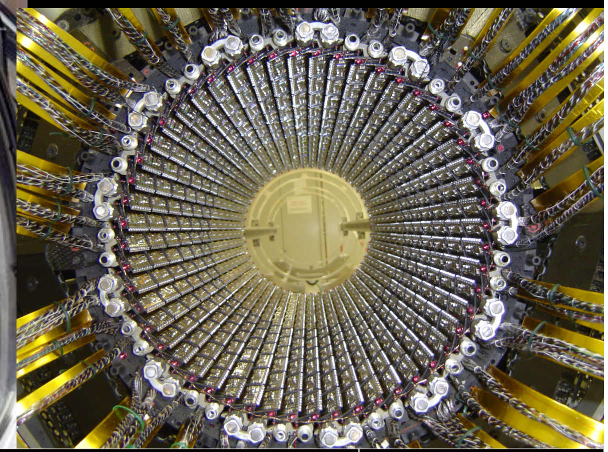
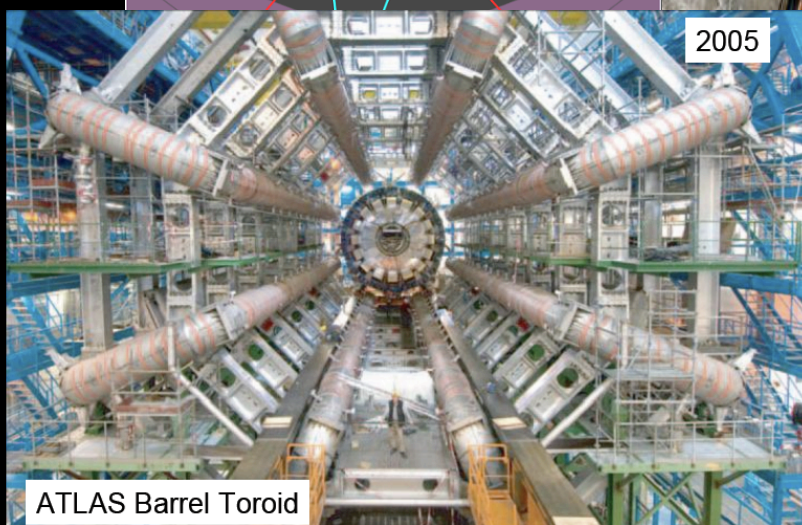
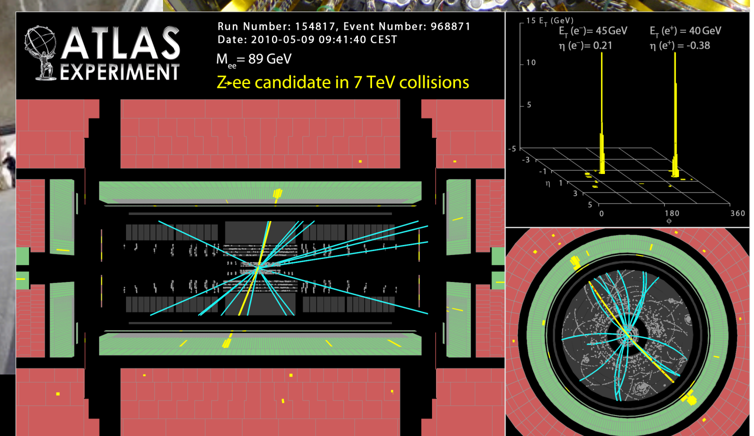
The ATLAS Experiment at LHC
Status and First Results











Beate Heinemann, UC Berkeley and LBNL

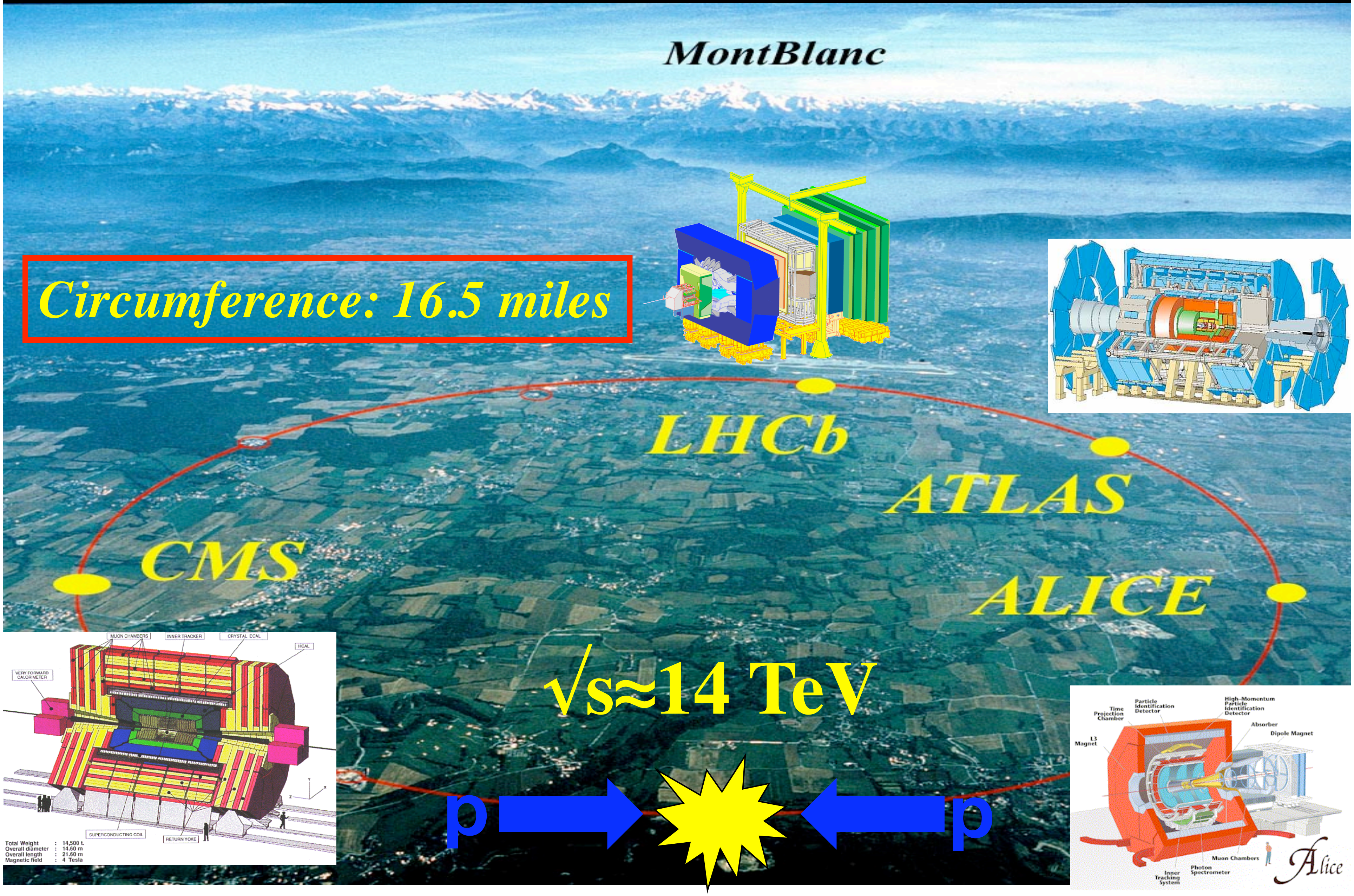
BNL, May 2010

Outline

- **The ATLAS Experiment**
  - Data Taking and Luminosity
  - Physics Goals
    - Brief reminder
  - Current Detector Performance
  - First Physics Results

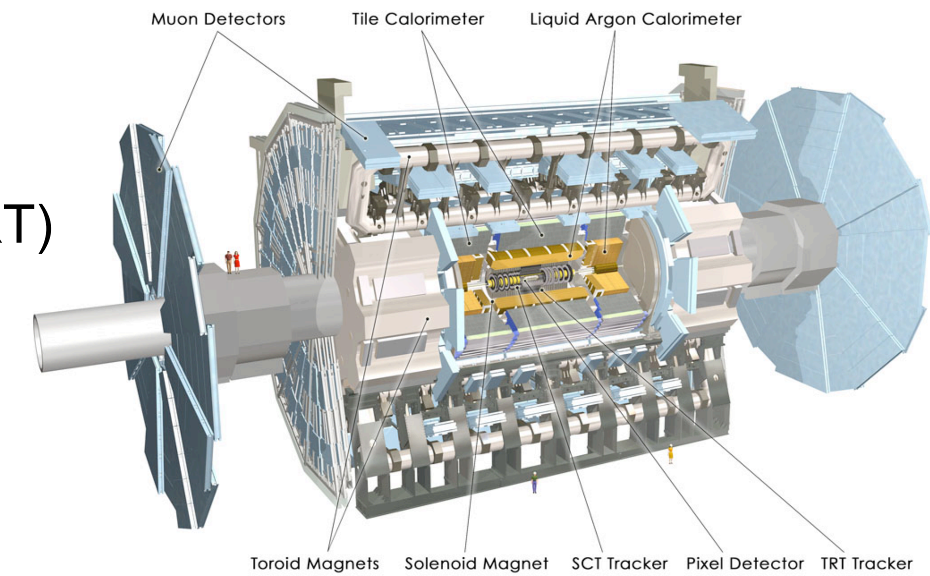
- **Conclusions and Outlook**

The Large Hadron Collider (LHC)

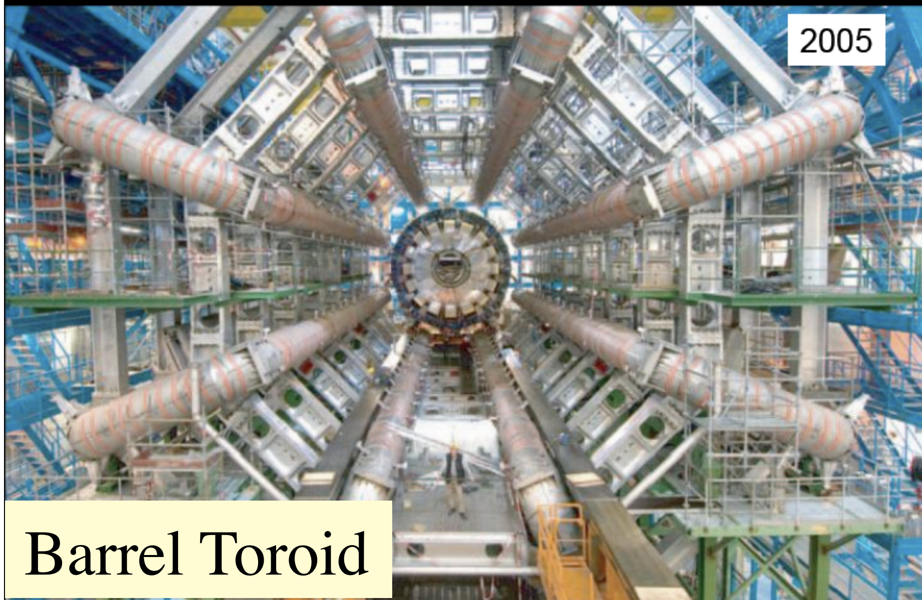


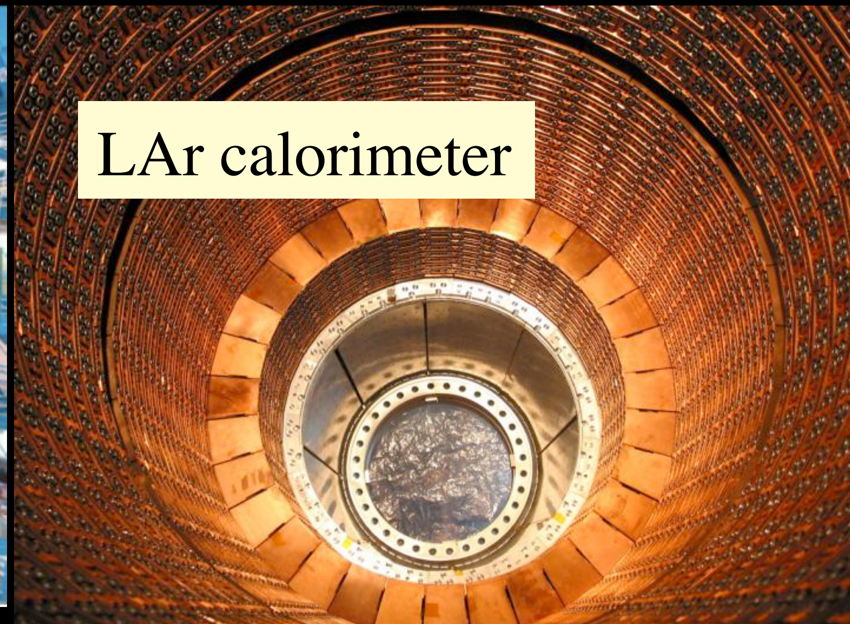
ATLAS at the LHC

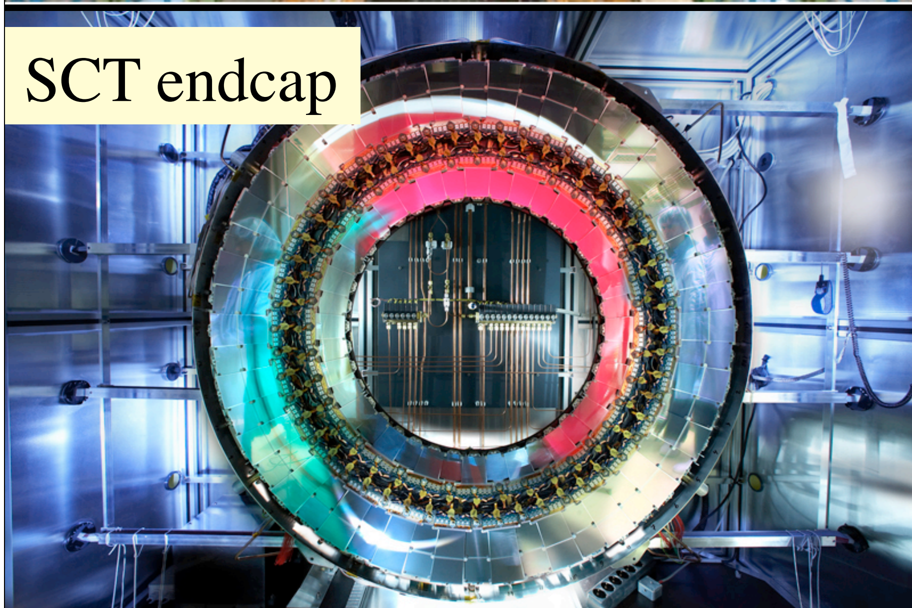
- **Inner Detector: |η|<2.5**
  - Silicon Pixels
  - Silicon Strips (SCT)
  - Transition Radiation Tracker (TRT)
  - Solenoidal magnet (B=2T)
- **Calorimeters: |η|<4.9**
  - EM: Lead/LAr
  - HAD: Steel/scintillator + Cu/LAr
- **Muon System: |η|<2.5**
  - Precision chambers (MDT and CSC)
  - Trigger chambers (RPC and TGC)
  - Air-core toroid magnet (∫BdL=1-7.5 Tm)
- **Several forward detectors**
  - Luminosity measurement

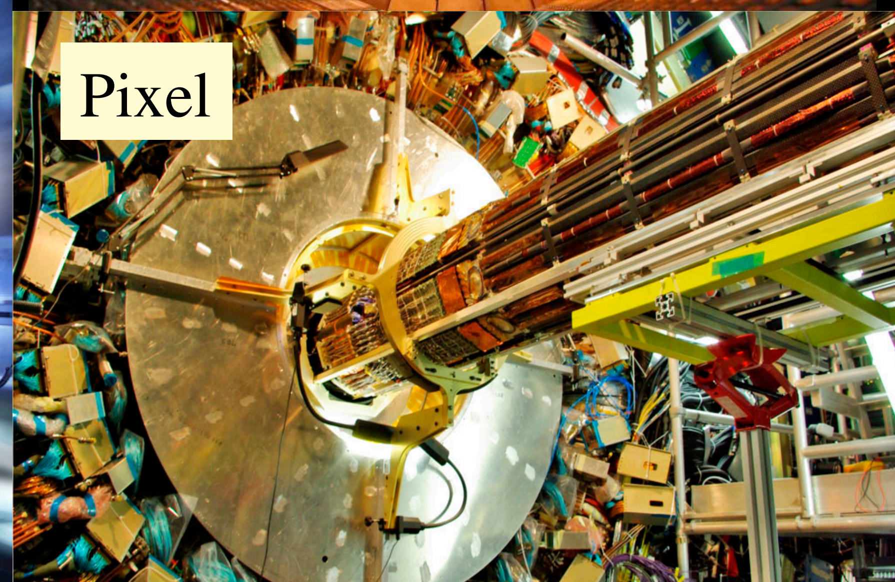


ATLAS Subdetectors









ATLAS Detector Operation

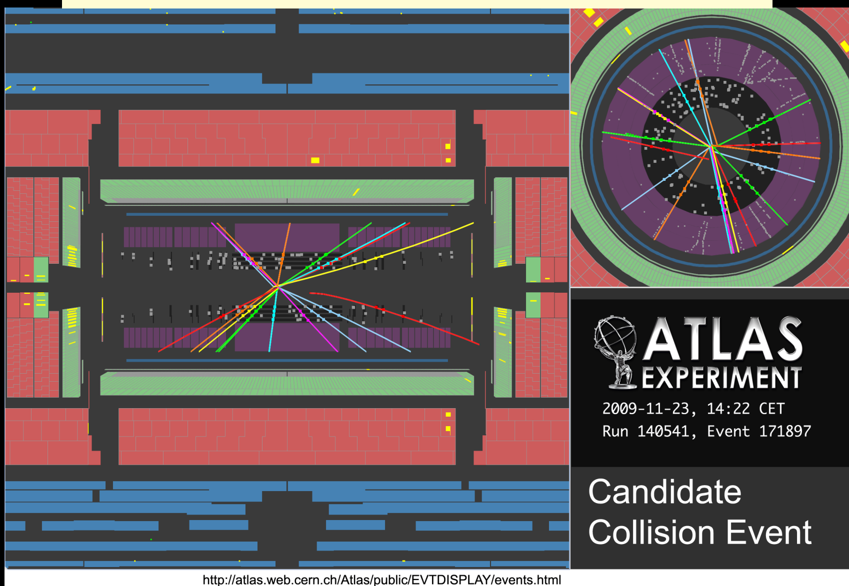
Subdetector	Number of Channels	Approximate Operational Fraction
Pixels	80 M	97.5%
SCT Silicon Strips	6.3 M	99.3%
TRT Transition Radiation Tracker	350 k	98.0%
LAr EM Calorimeter	170 k	98.5%
Tile calorimeter	9800	97.3%
Hadronic endcap LAr calorimeter	5600	99.9%
Forward LAr calorimeter	3500	100%
LVL1 Calo trigger	7160	99.8%
LVL1 Muon RPC trigger	370 k	99.7%
LVL1 Muon TGC trigger	320 k	100%
MDT Muon Drift Tubes	350 k	99.7%
CSC Cathode Strip Chambers	31 k	98.5%
RPC Barrel Muon Chambers	370 k	97.3%
TGC Endcap Muon Chambers	320 k	98.8%

All ATLAS subdetectors operate 97-100% of their channels

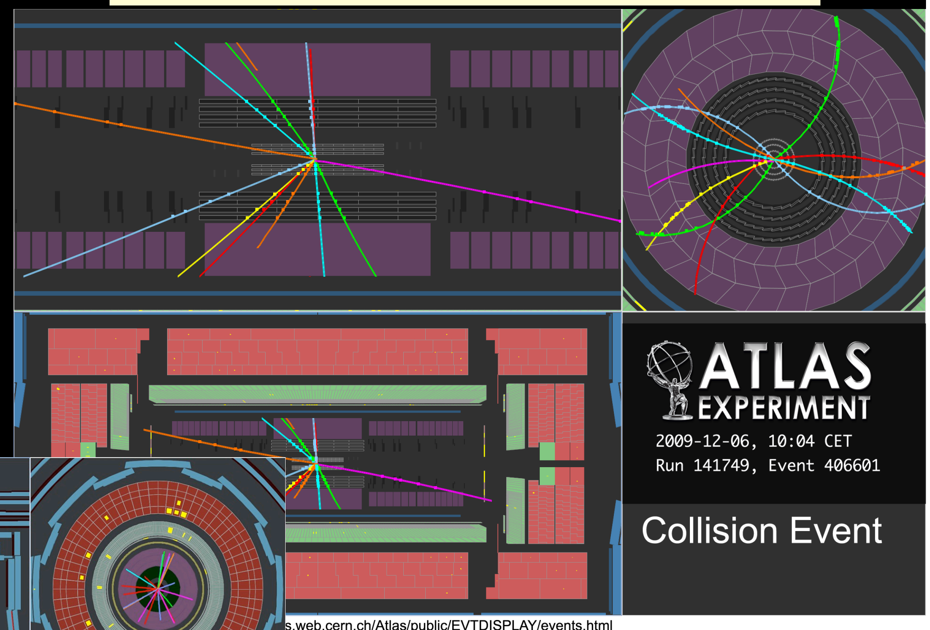

!!! BEAM AT ATLAS !!!
20-11-09 20:47

Collisions in ATLAS!!

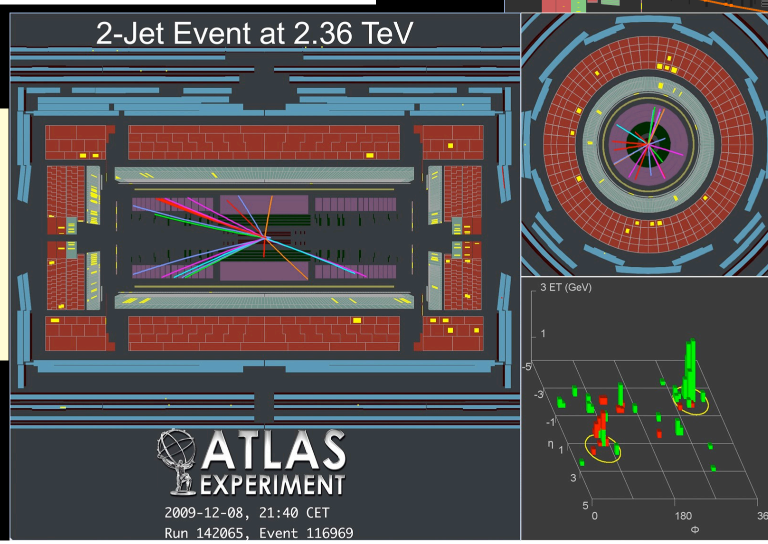
Nov. 23rd: first collisions



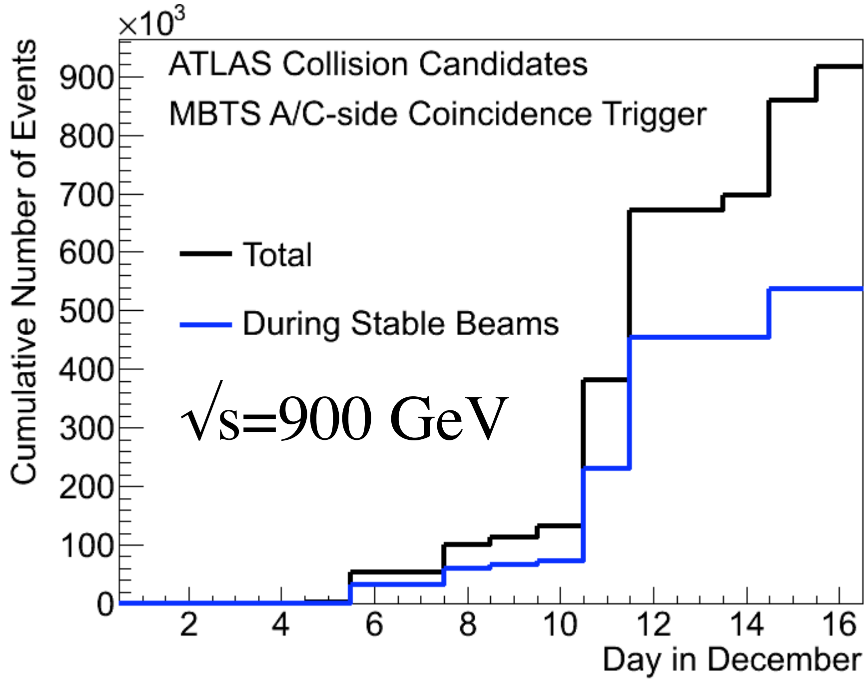
Dec. 6th: first collisions with full detector in nominal conditions



Dec. 8th : first Collisions at $\sqrt{s}$=2.36 TeV



Summary of 2009 Data Taking

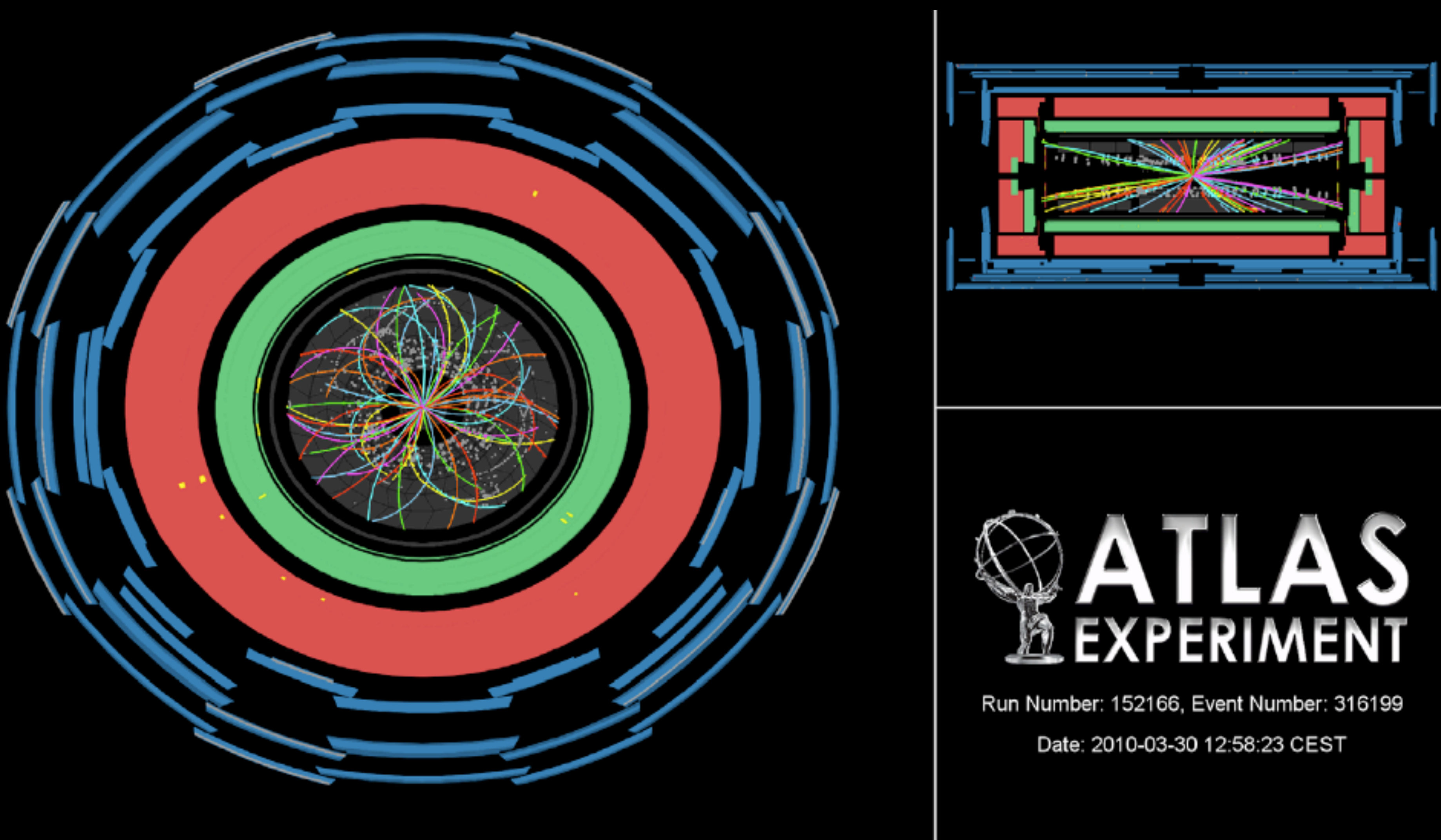


Peak Luminosity
7×10^{26} cm^{-2}s^{-1}

Recorded data samples	Number of events	Integrated luminosity (< 30% uncertainty)
Total	~ 920k	~ 20 μb^{-1}
With stable beams	~ 540k	~ 12 μb^{-1}
At √s=2.36 TeV	~ 34k	≈ 1 μb^{-1}

(First 2010 collisions at √s=2.36 TeV taken on March 14th)

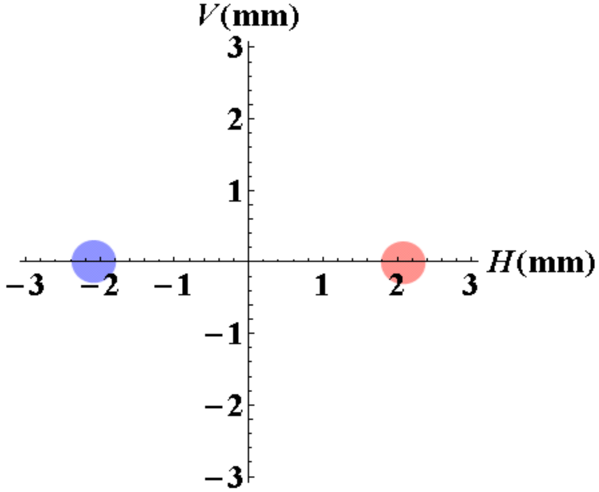
7 TeV Collision: March 30th



March 30 2010

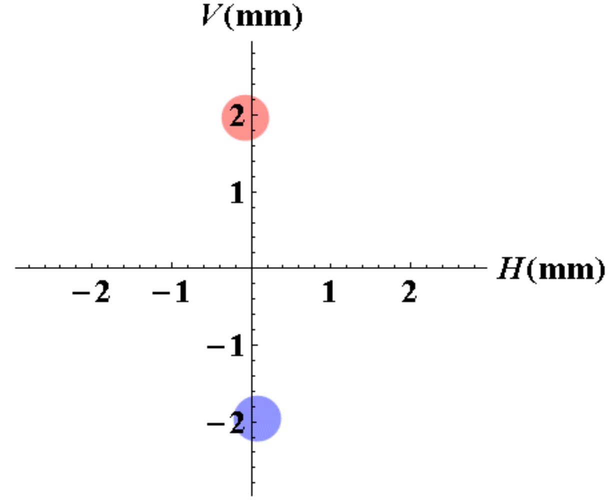
ATLAS IP Separation

H = 4.170 mm : V = 0.021 mm

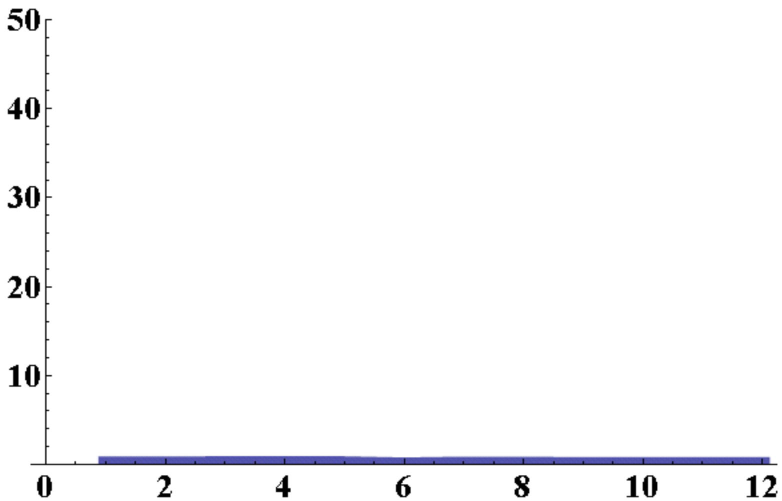


CMS IP Separation

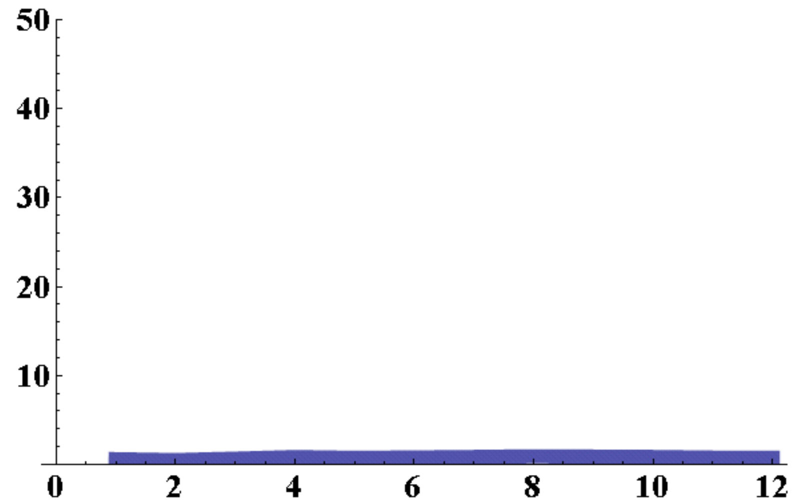
H = 0.139 mm : V = 3.924 mm



ATLAS Coll Rate Evol



CMS Coll Rate Evol



Celebrating 7 TeV Collisions

Luminosity

- Single most important quantity
  - Drives our ability to detect new processes

$$L = \frac{f_{rev}\, n_{bunch}\, N_p^{\,2}}{4\,\pi\,\sigma_x\,\sigma_y}$$

revolving frequency: f_{rev}=11245.5/s
#bunches: n_{bunch}=2808
#protons / bunch: N_p= 1.15 x 10^{11}
Area of beams: $4\pi\sigma_x\sigma_y$~40 μm

  - Rate of physics processes per unit time directly related:

$$N_{obs} = \int L dt \cdot \varepsilon \cdot \sigma$$

Efficiency: optimized by experimentalist

Cross section σ: Given by Nature (calc. by theorists)

Ability to observe something depends on N_{obs}

Instantaneous Luminosity

$$L = \frac{N^2 k_b f}{4\pi\sigma_x\sigma_y} F = \frac{N^2 k_b f\gamma}{4\pi\varepsilon_n\beta^*} F$$

- Nearly all the parameters are variable
  - Number of particles per bunch N
  - Number of bunches per beam k_b
  - Relativistic factor (E/m_0) γ
  - Normalised emittance ε_n
  - Beta function at the IP β^*
  - Crossing angle factor F
    - Full crossing angle θ_c
    - Bunch length σ_z
    - Transverse beam size at the IP σ^*

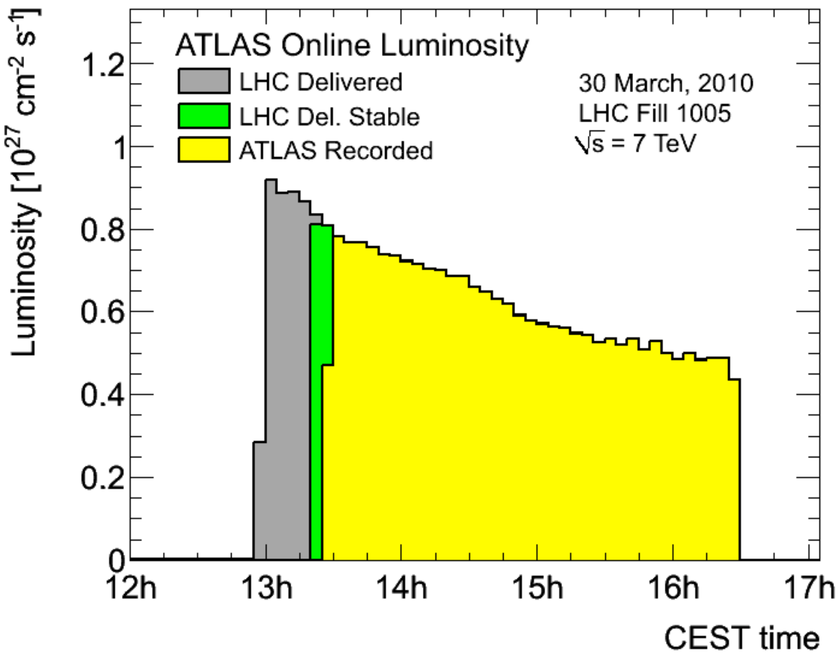
$\left.\begin{array}{l} N \\ k_b \end{array}\right\}$ Intensity

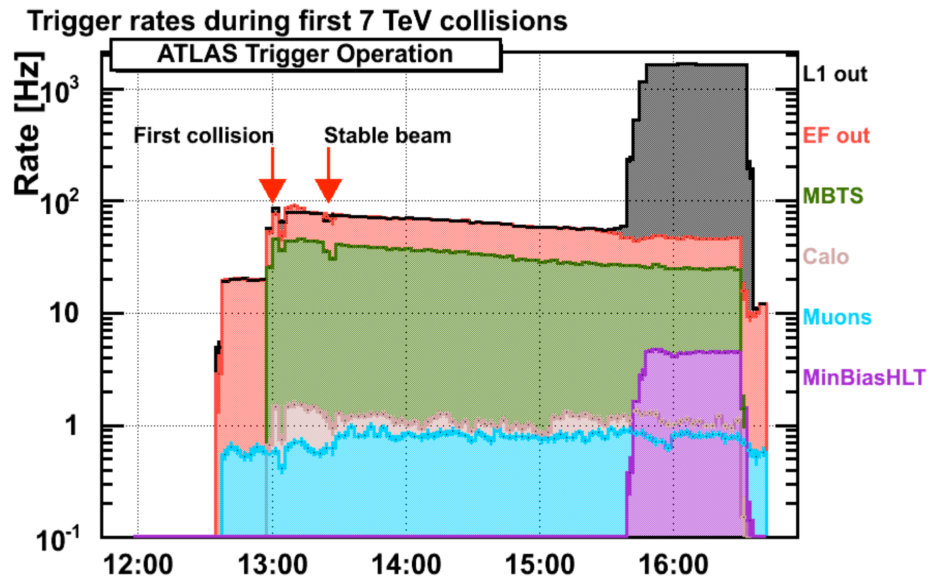
γ — Energy

$\left.\begin{array}{l} \varepsilon_n \\ \beta^* \end{array}\right\}$ Interaction Region

$$F = 1\Big/\sqrt{1 + \left(\frac{\theta_c\sigma_z}{2\sigma^*}\right)^2}$$

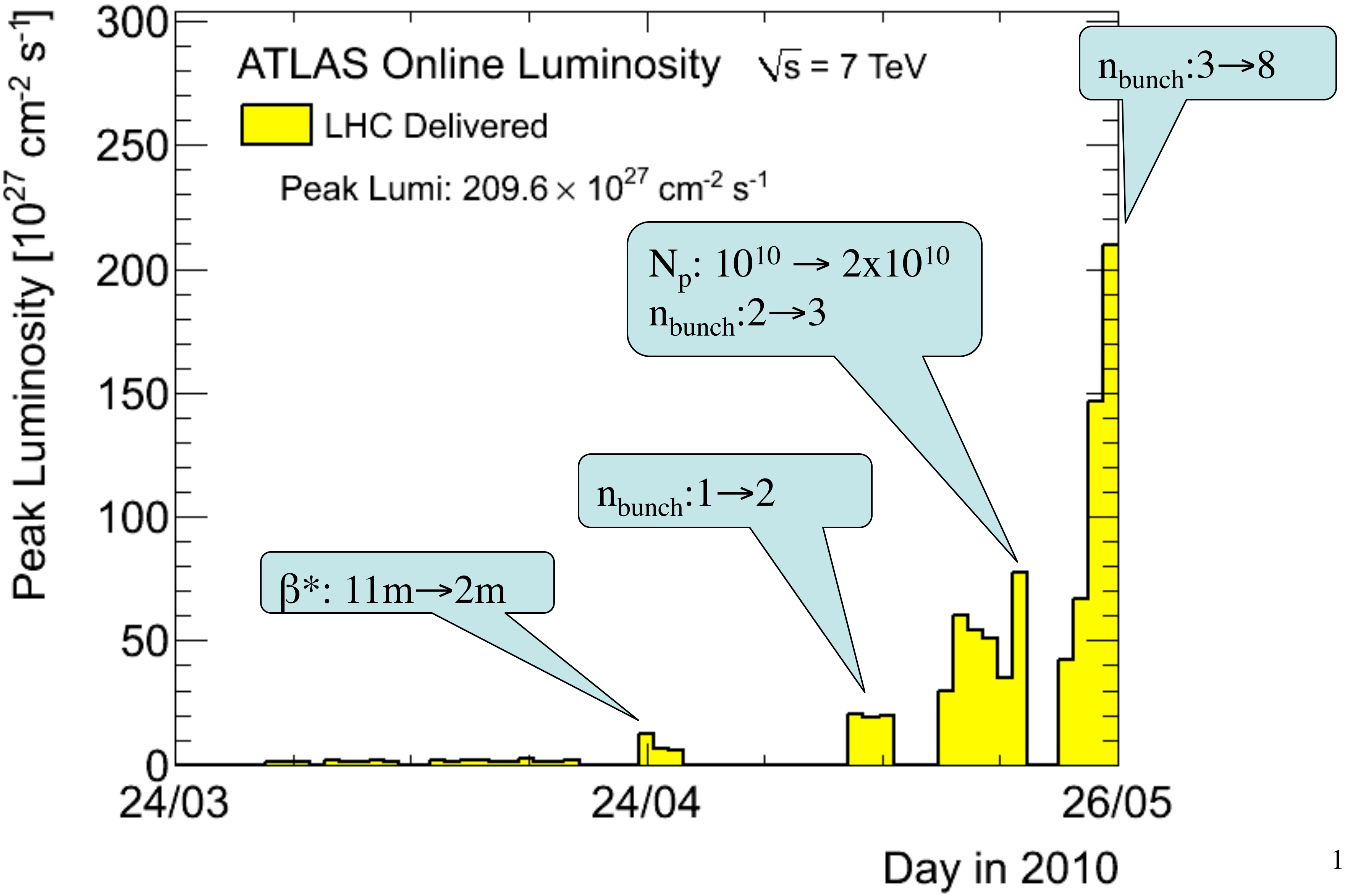
ATLAS during First 7 TeV Collisions



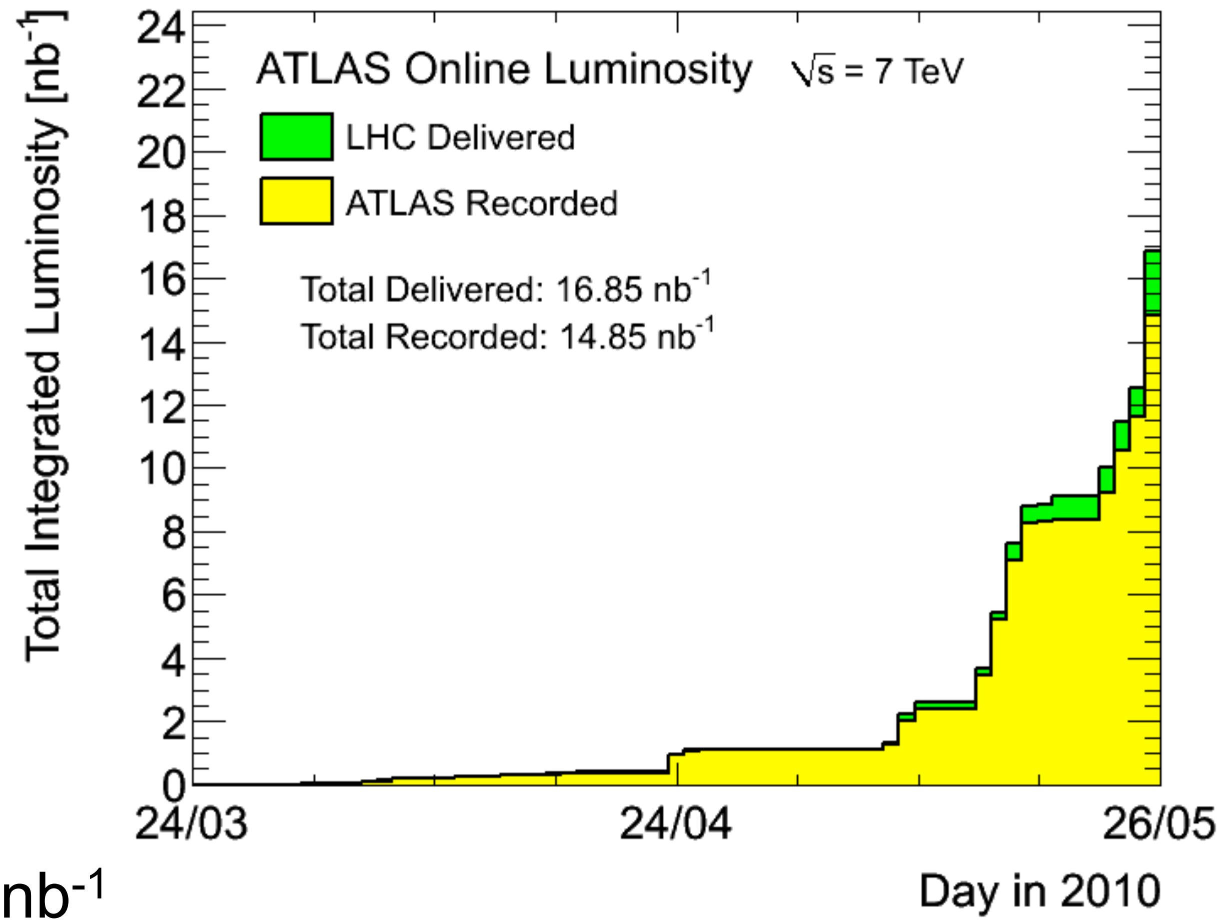


- Data all taken efficiently
  - Minimum bias is taken at full rate during first fill
  - High-level trigger (software-based) turned on after a few hours

Peak Luminosity Evolution



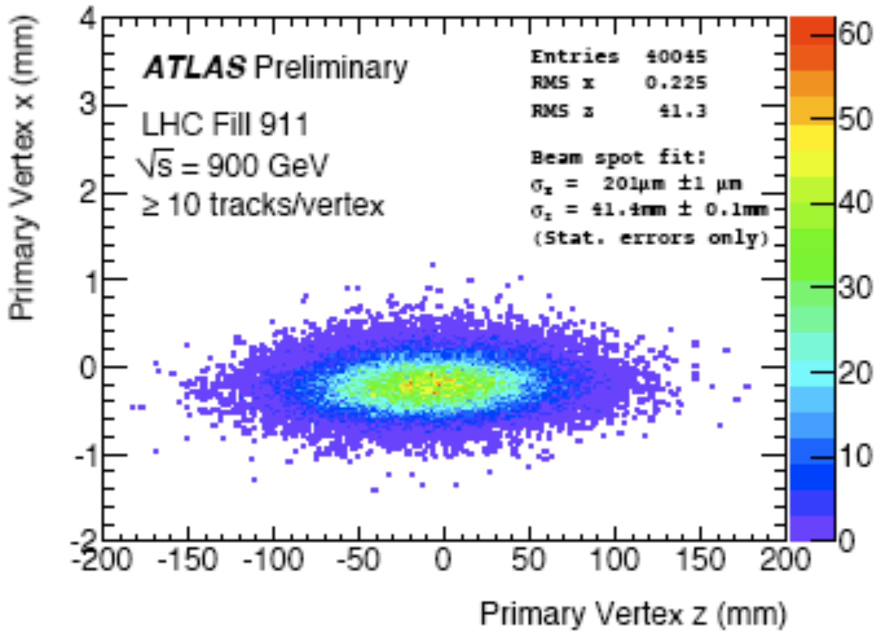
Integrated Luminosity



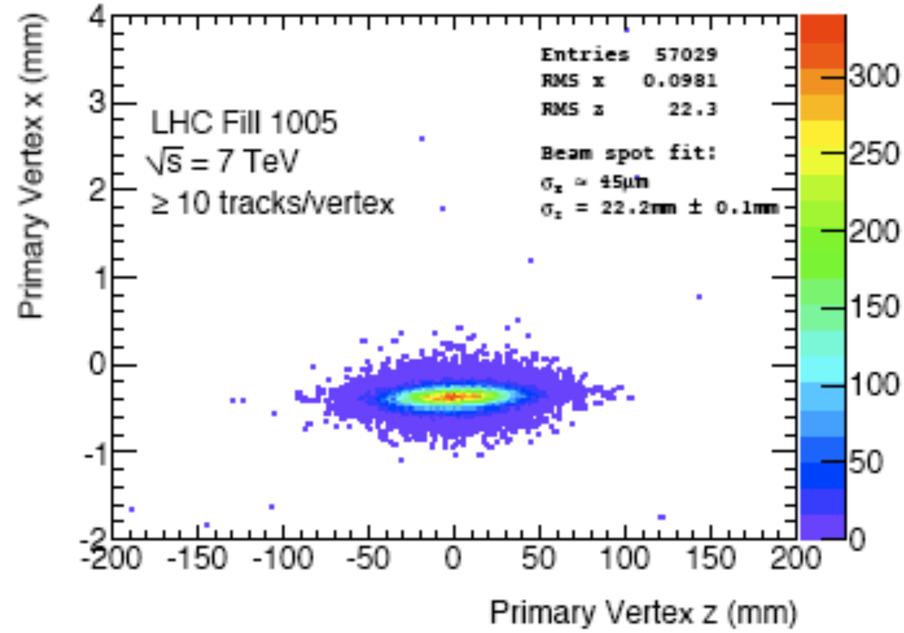
- Delivered: 16.9 nb^{-1}
- ATLAS recorded: 14.9 nb^{-1} (ε=88%)
  - Inefficiency about 50% due Trigger deadtime and 50% due to subdetectors turning on/having problems

Beamspot in ATLAS

√s=0.9 TeV

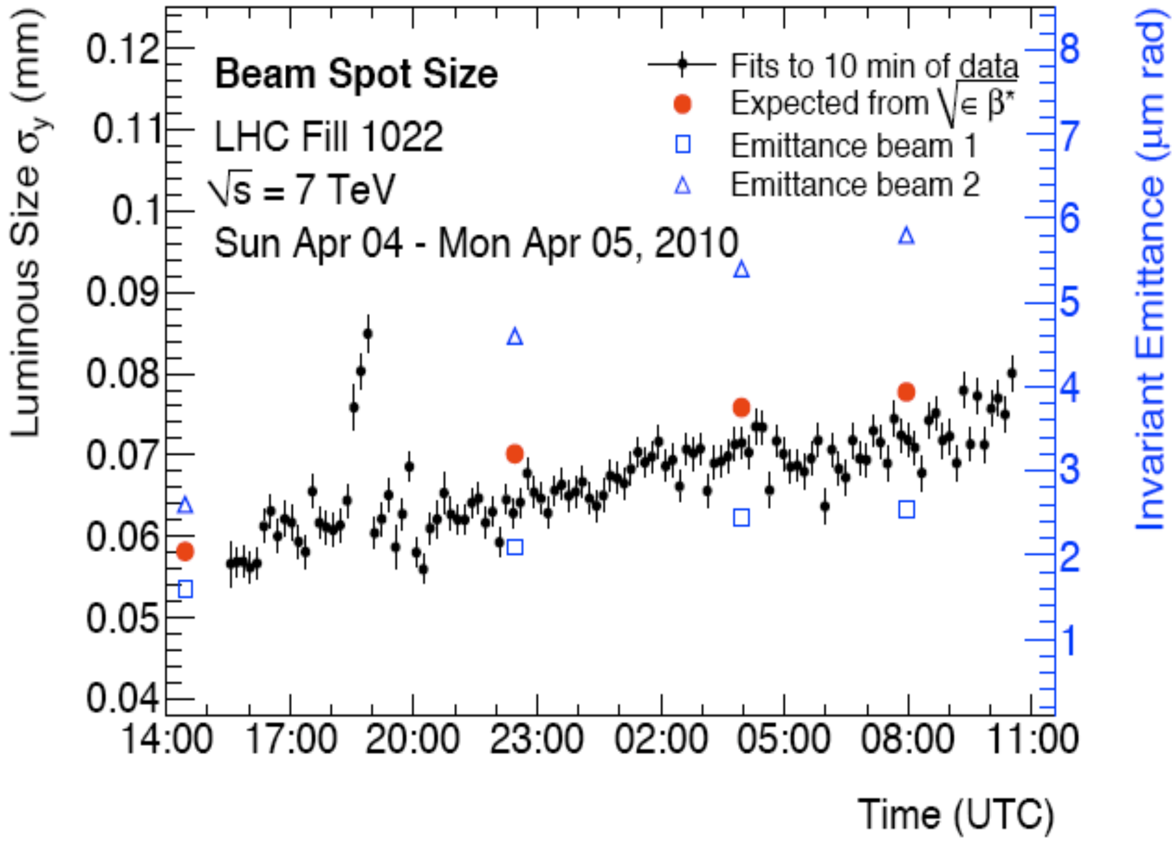


√s=7 TeV



- Expected to decrease with 1/√s observed:
  - 900 GeV: σ_x=200 μm
  - 7 TeV: σ_x= 75 μm

Beamspot vs √εβ*



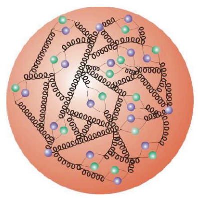
- Measured beamspot size consistent with accelerator measurements
  - Relation: $\gamma\varepsilon\beta^*=\sigma^2$

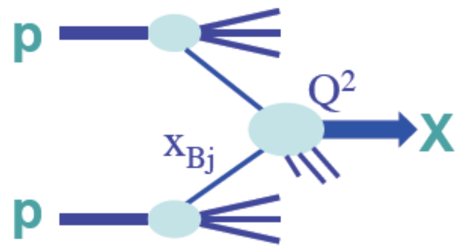
Physics Discovery Potential

(very brief reminder)

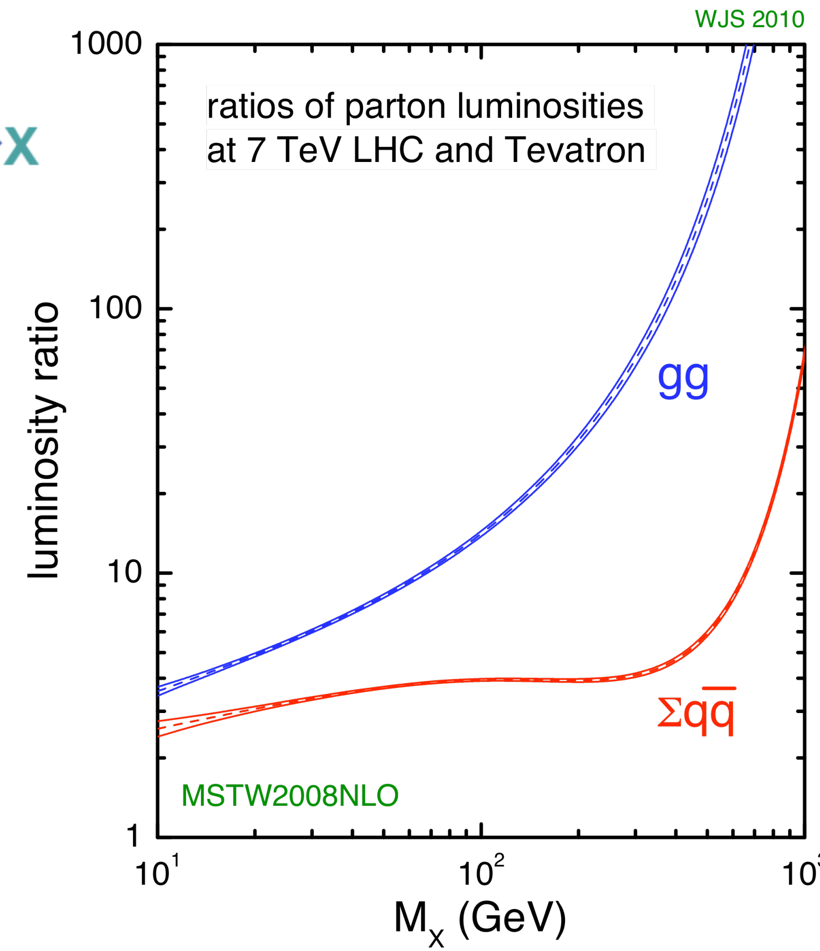
Physics Cross Sections

$$M_X = \sqrt{x_1 \cdot x_2 \cdot s}$$





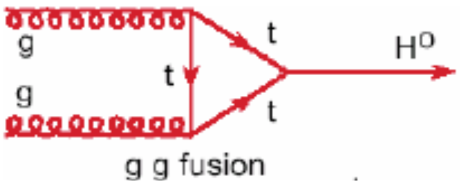
Process	M_X	$\frac{\sigma(\text{LHC @ 7 TeV})}{\sigma(\text{Tevatron})}$
$q\bar{q}\to W$	80 GeV	3
$q\bar{q}\to Z'_{SM}$	1 TeV	50
$gg\to H$	120 GeV	20
$q\bar{q}/gg \to t\bar{t}$	2x173 GeV	15
$gg \to \tilde{g}\tilde{g}$	2x400 GeV	1000

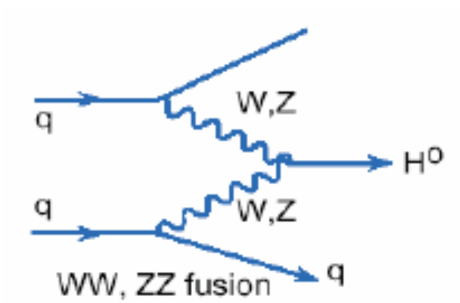


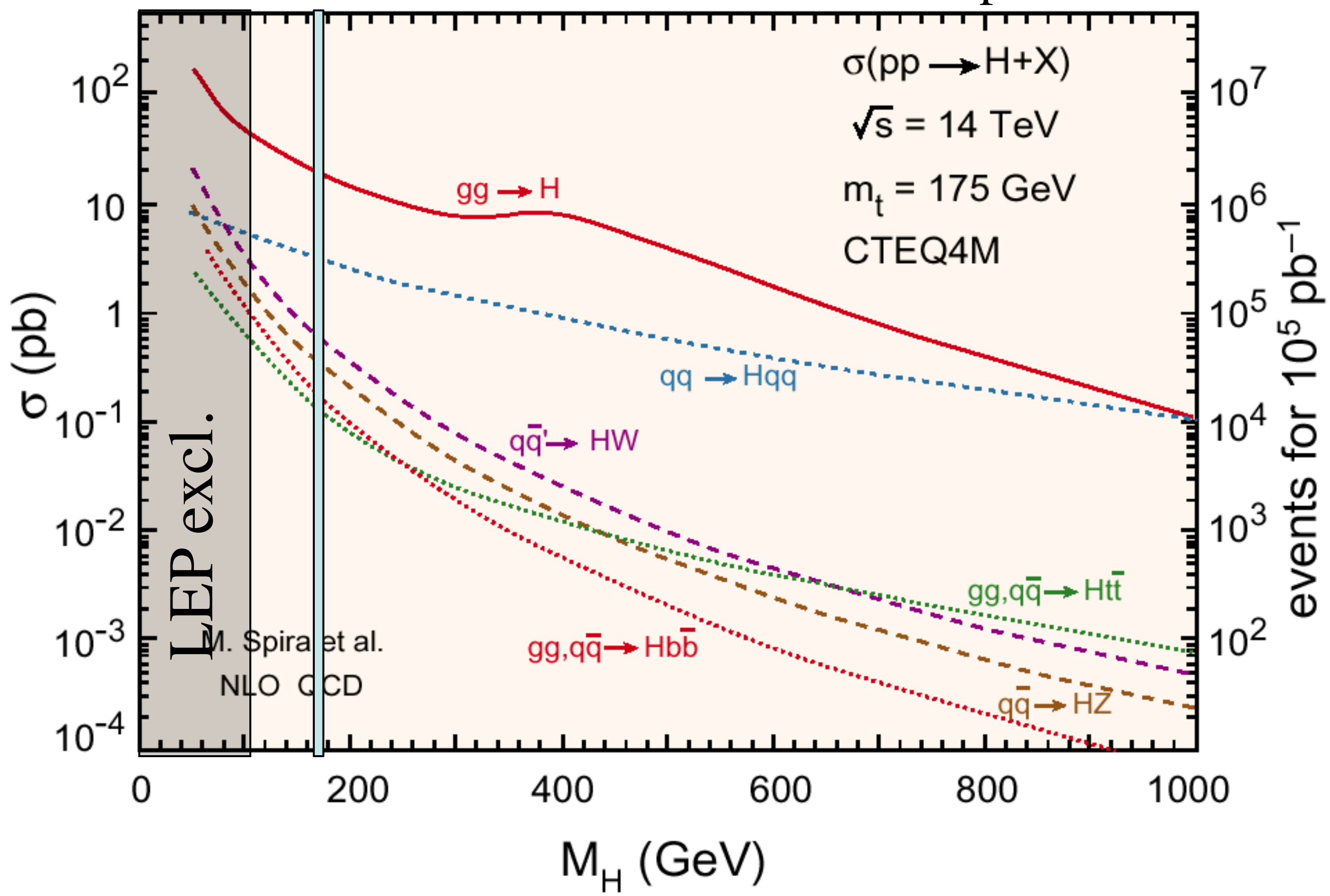
- $\int$Ldt=1 fb^{-1} at LHC competitive with 10 fb^{-1} at Tevatron for high mass processes

Higgs Production at the LHC

M. Spira *et al.*

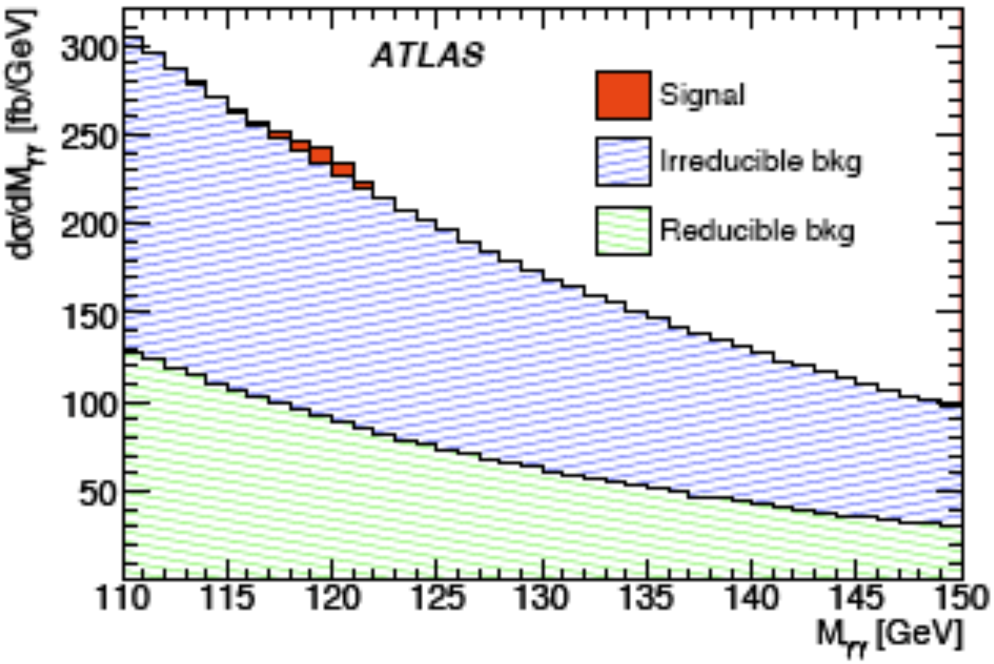




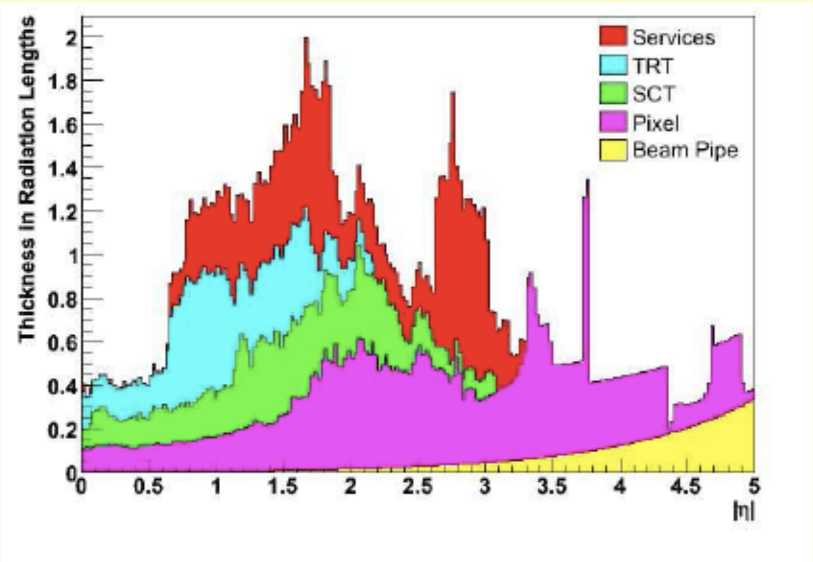


dominant: gg→ H, subdominant: Hqq (VBF)

Low Mass Higgs at LHC



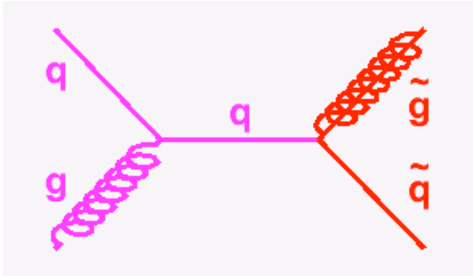
Material (X_0) in front of Calorimeters versus η



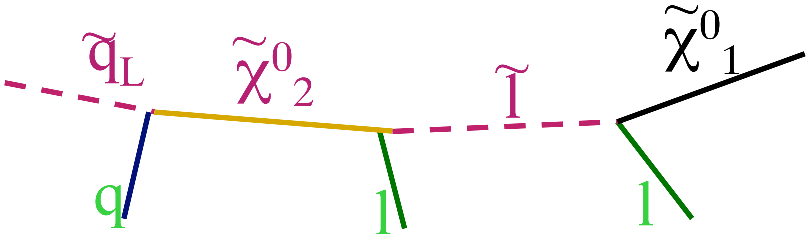
- H→γγ challenges:
  - Large background qq→γγ and from jets (with $\pi^0 \rightarrow \gamma\gamma$)
  - Mass resolution is key: requires brilliant calibration
  - At least 1 photon converts in 50% of events
    - Important to understand detector material
- VBF: Hqq→ττqq also very promising and important channel

Squarks and Gluinos at the LHC

- Cross sections depends on $\tilde{q}/\tilde{g}$ mass
  - Current limits: $m(\tilde{g})>300$ GeV
  - Increase large compared to Tevatron

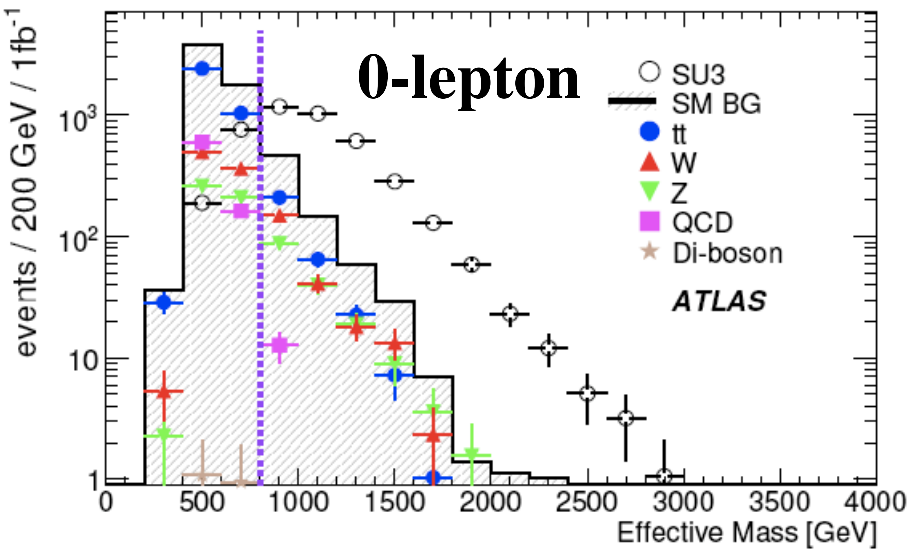


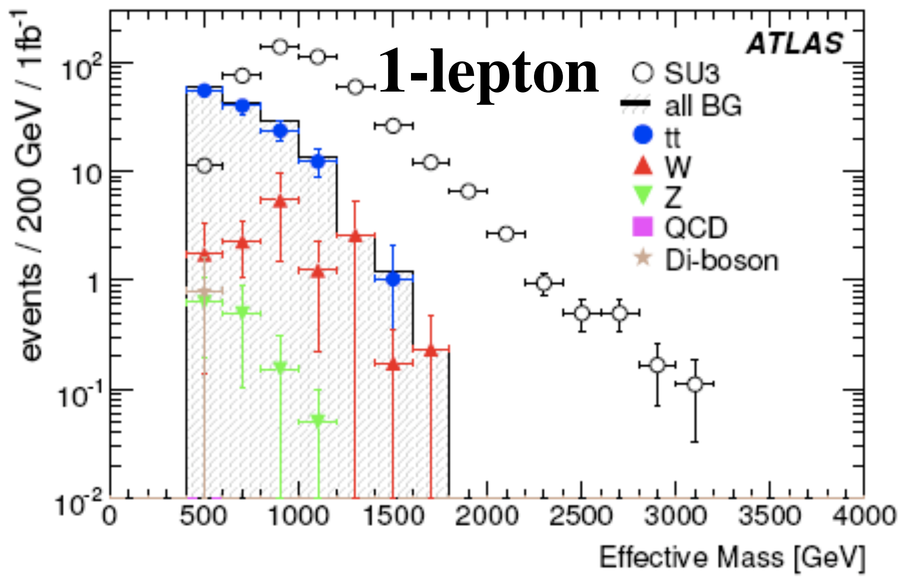
- May decay in cascades
  - Additional leptons or jets
  - Very model-dependent



- Search requires good understanding of
  - Leptons (e, μ and τ)
  - Jets (with and without b-tagging)
  - Missing E_T (due to LSP if R-parity conserved)
  - And need to trigger reliably on all of the above

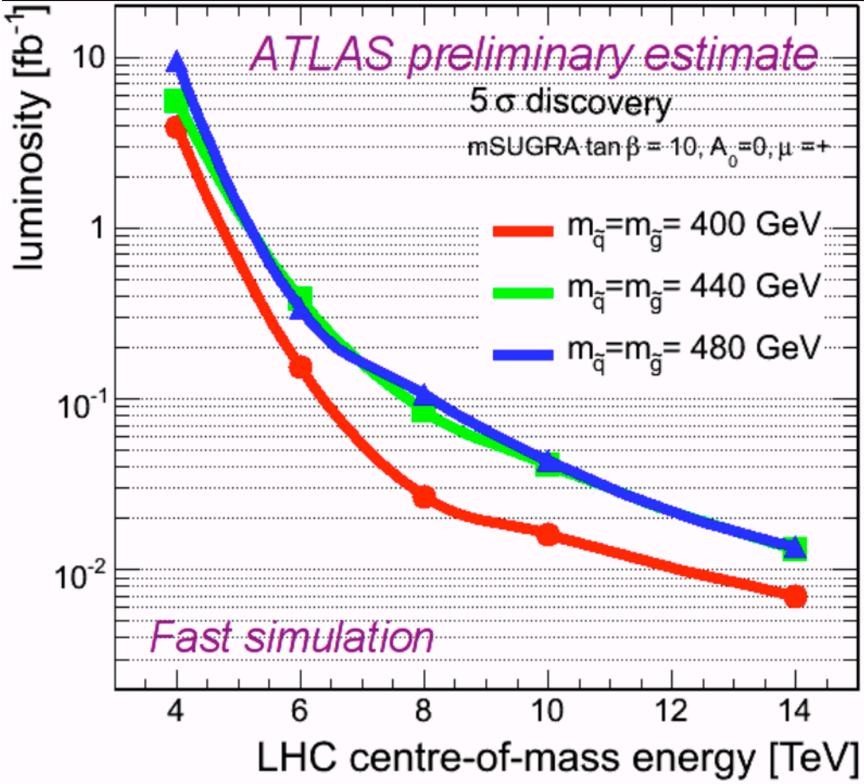
Search Analyses: 0, 1, 2.. leptons+jets

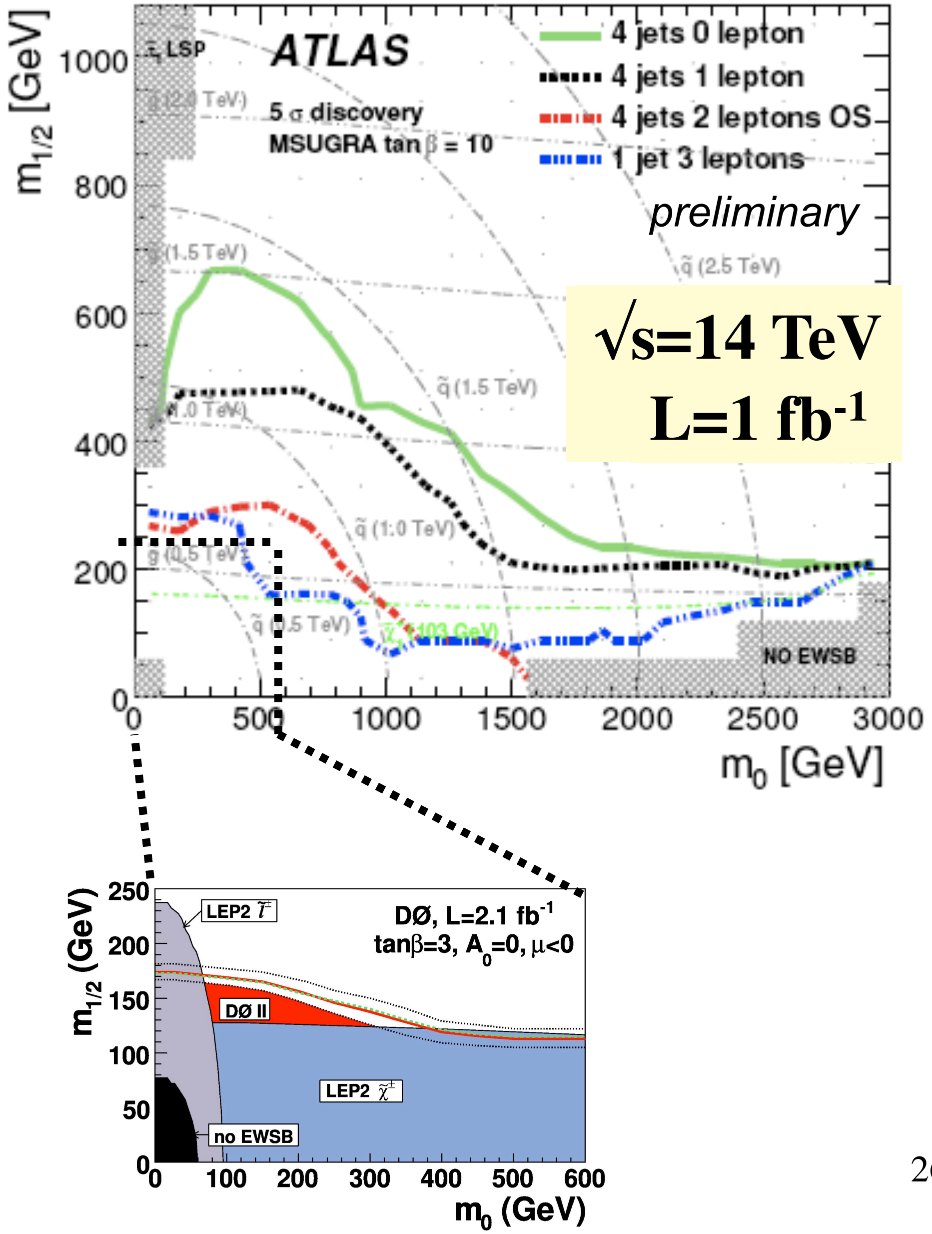




- Signal can appear in many search analyses simultaneously
  - Depends on model details
  - Important to do all of them
- Top is most severe background in general

LHC SUSY Discovery Reach

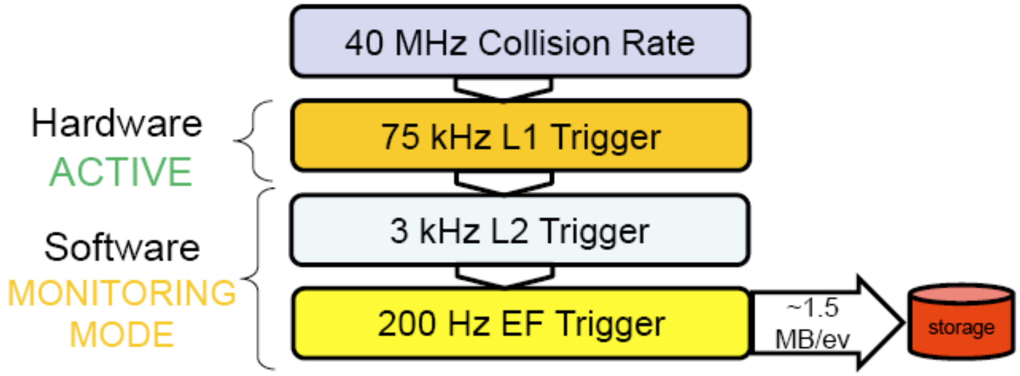




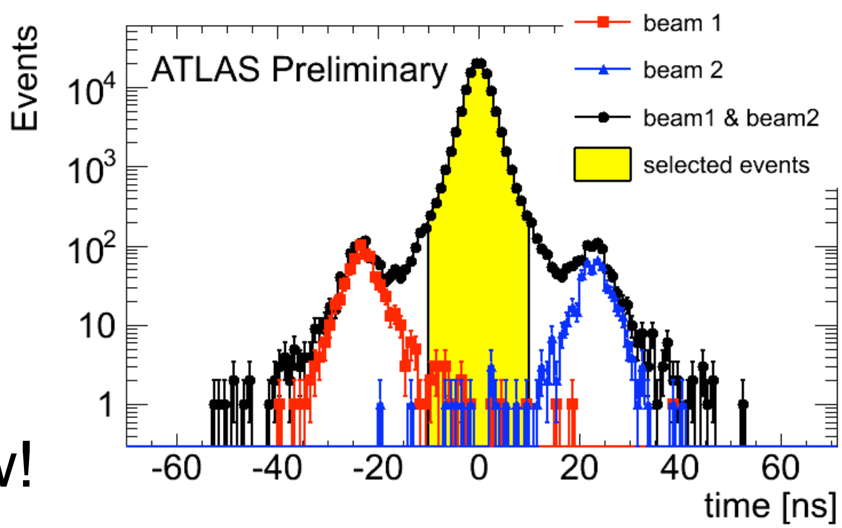
- Current limits (Tevatron):
  - m($\tilde{g}$)>300-400 GeV/c^2
  - LHC will surpass with ~0.1 fb^{-1}

Performance and First Results

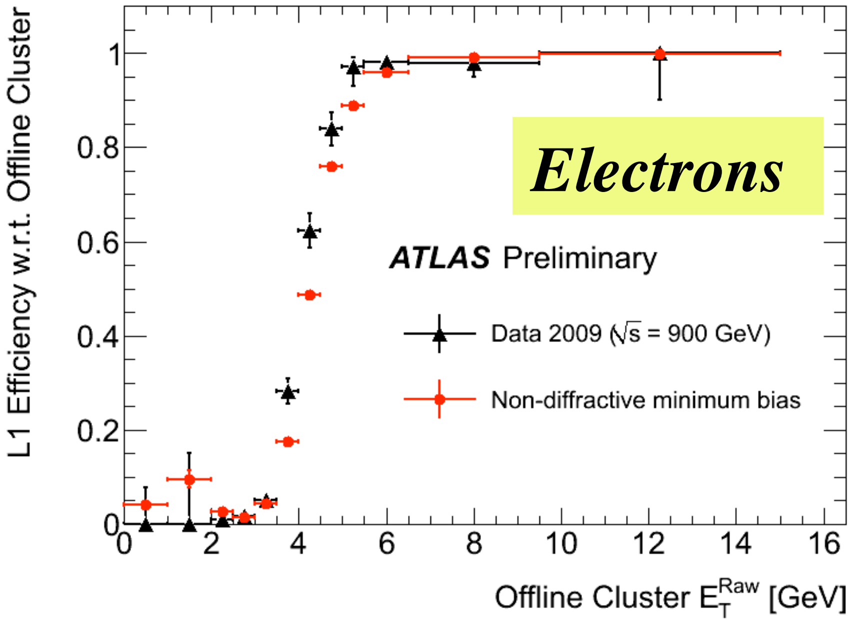
Trigger

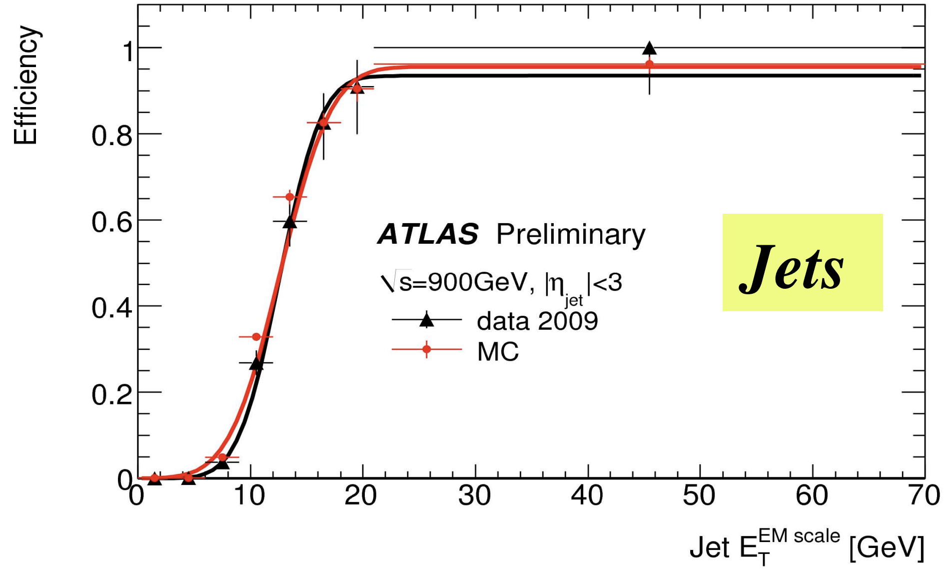


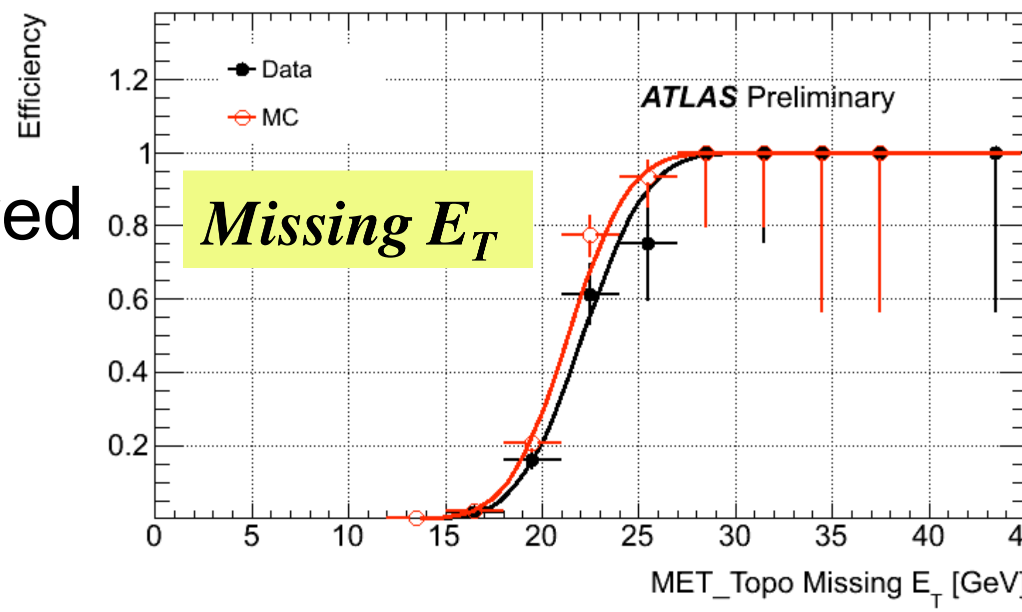
- 2009:
  - Typical L1 rate 20 Hz
- 2010:
  - First run: 50 Hz
  - Recent runs: ~10 kHz
    - MinBias is prescaled now!



Trigger Efficiencies

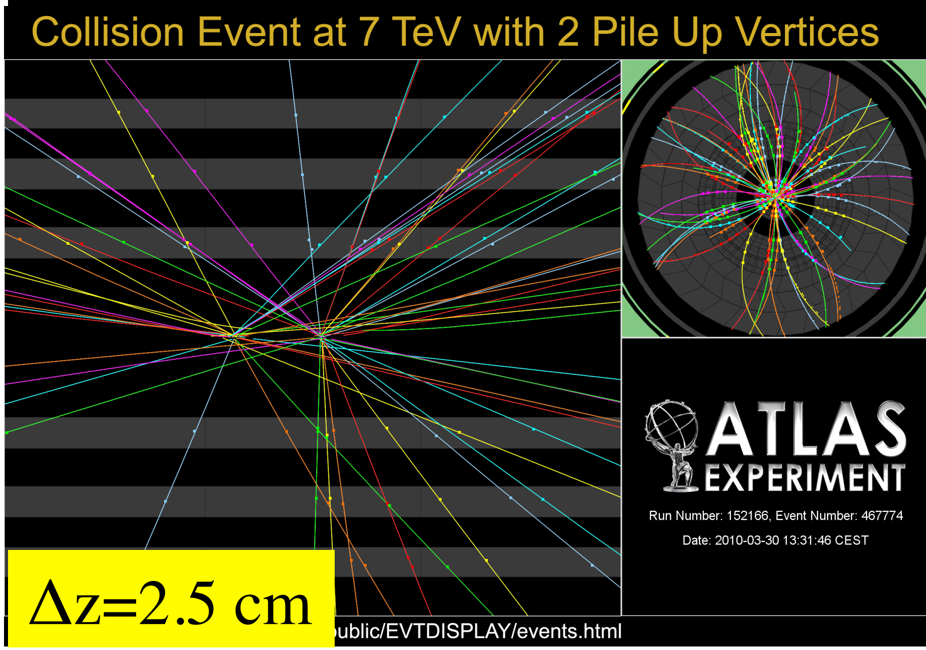


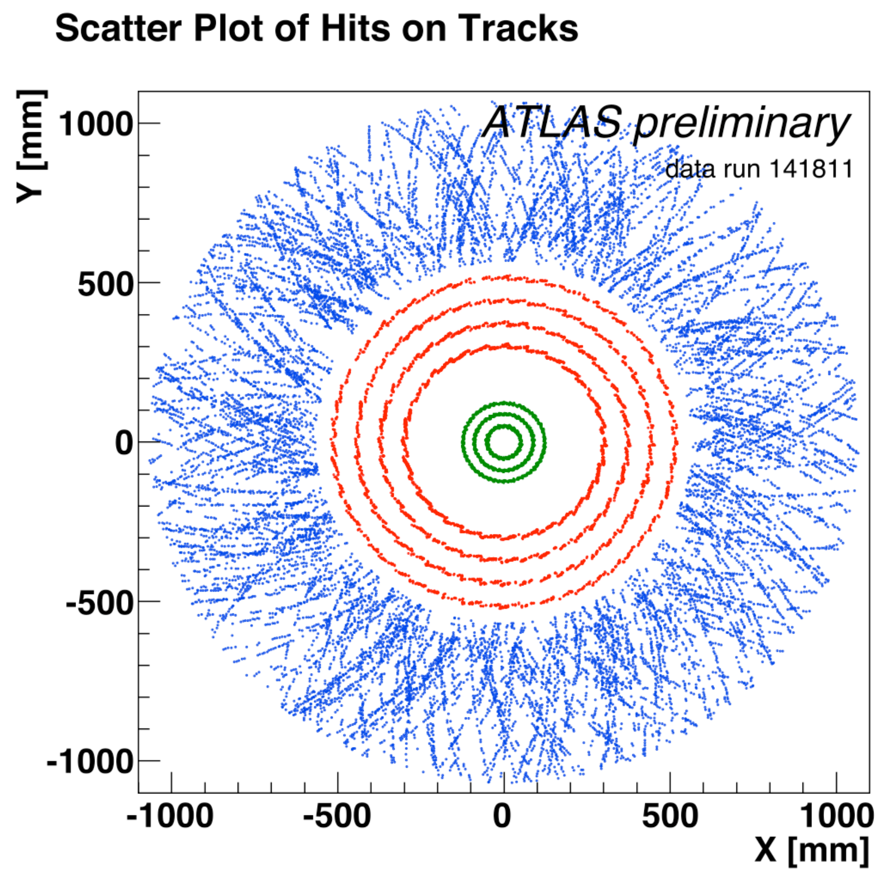




- Efficiencies well behaved
- Trigger generally operating very well

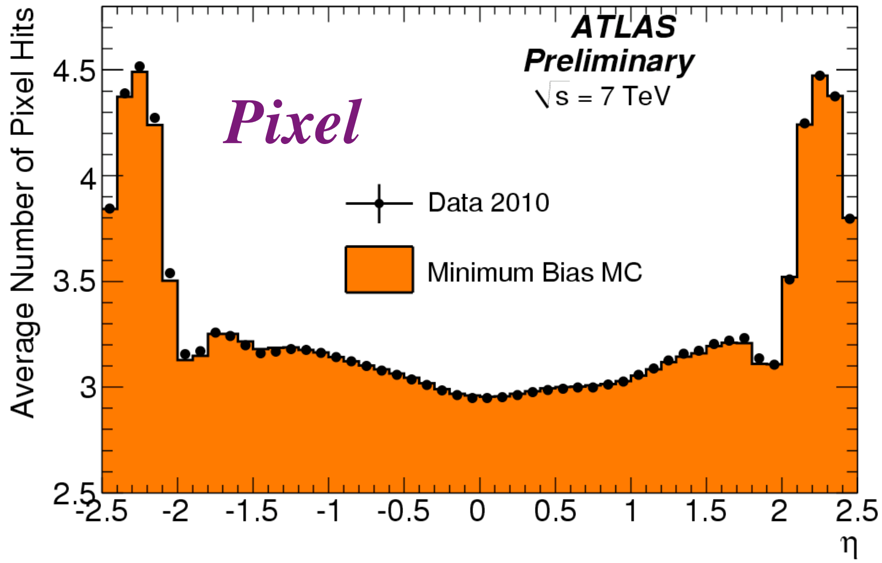
Tracking

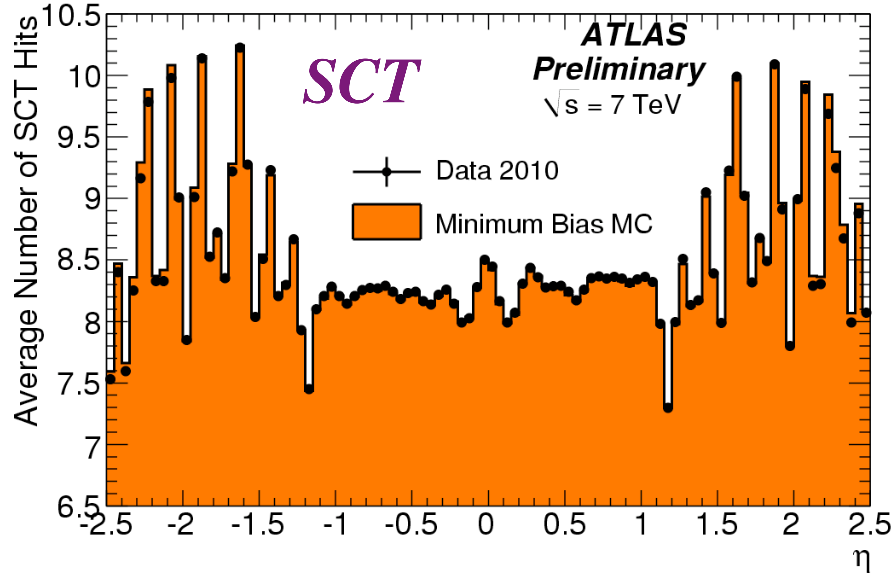




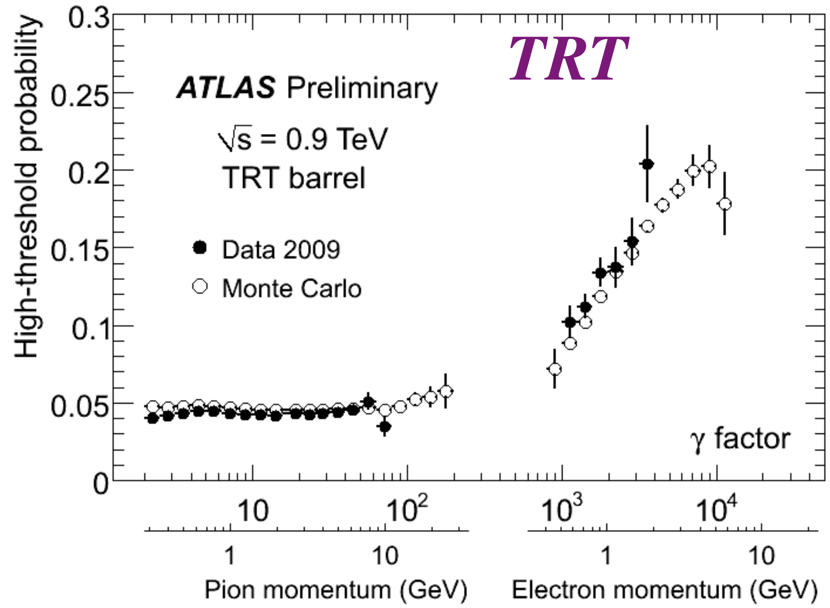
- Center of experiment
- Crucial for b-tagging, lepton/γ ID,…
- First ATLAS physics paper based primarily on tracking

Pixel, SCT, TRT Hit Distributions

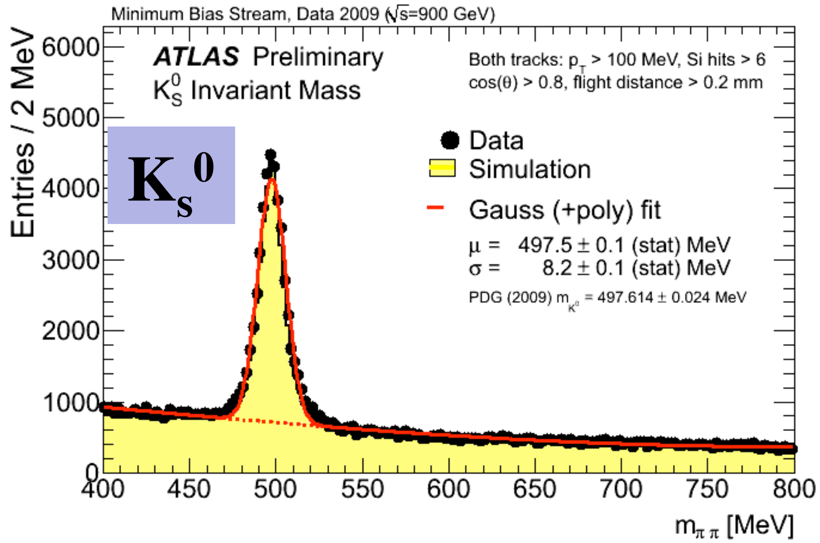


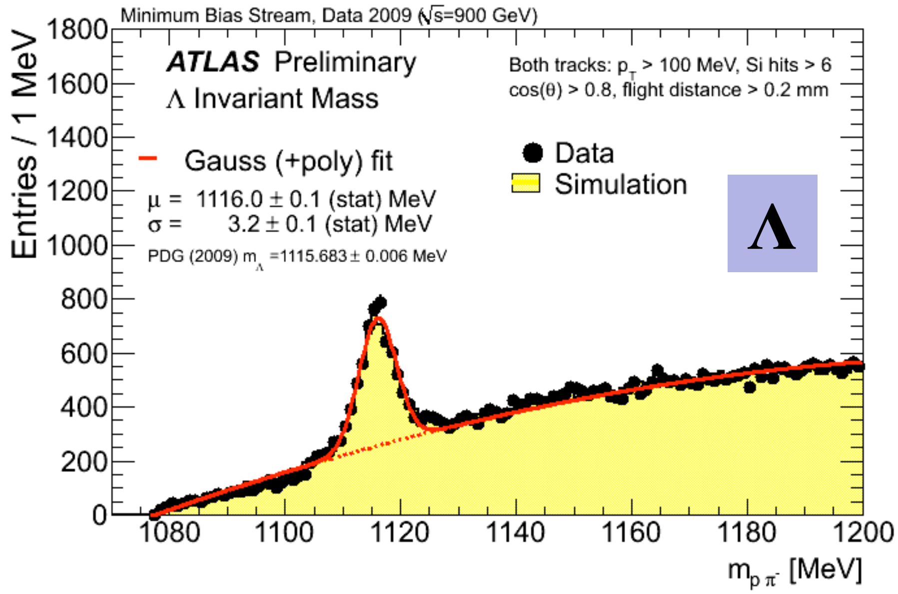


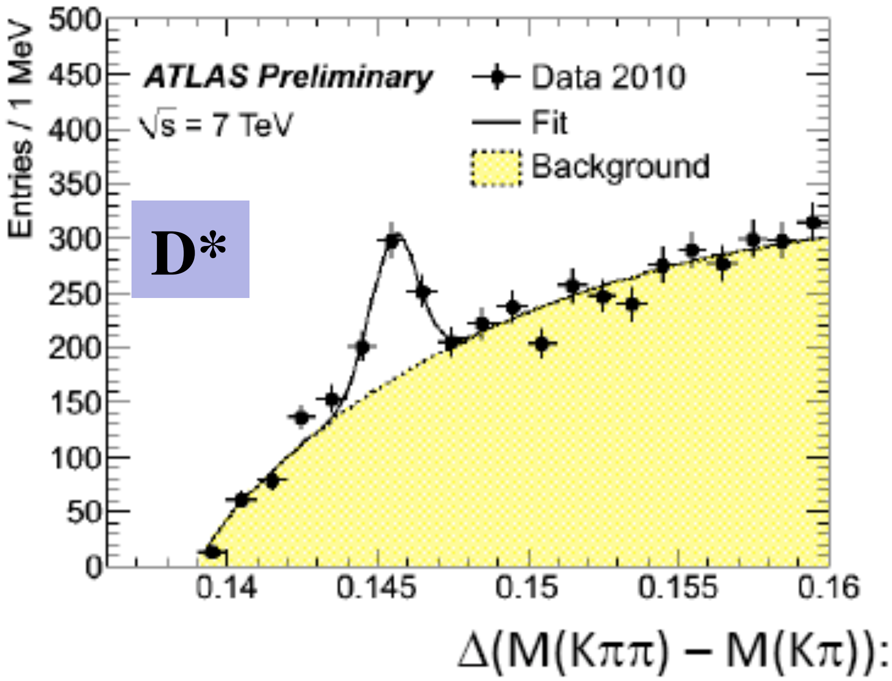
- Excellent agreement between data and simulation



Resonances: K_s^0,Λ, D*

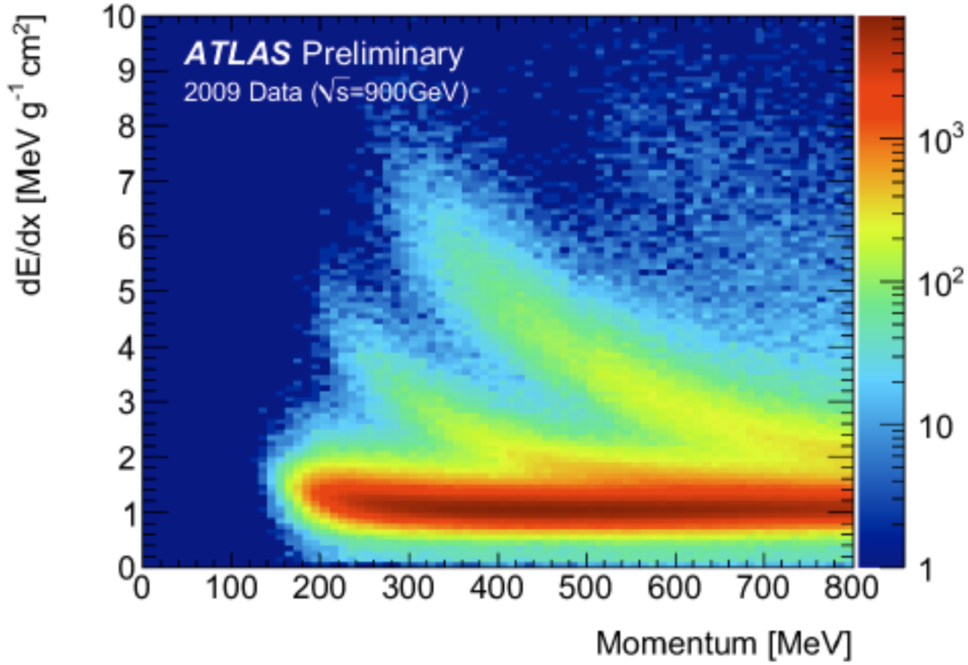






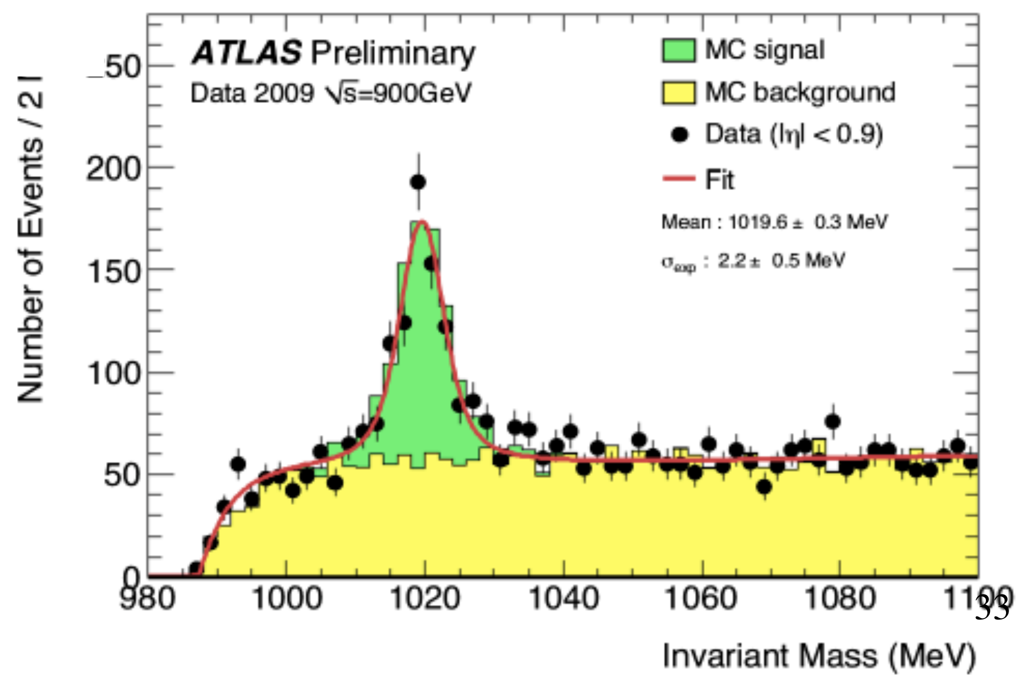
- Results agree with expectation and simulation
  - Both position and width well understood

Particle Identification with Pixels

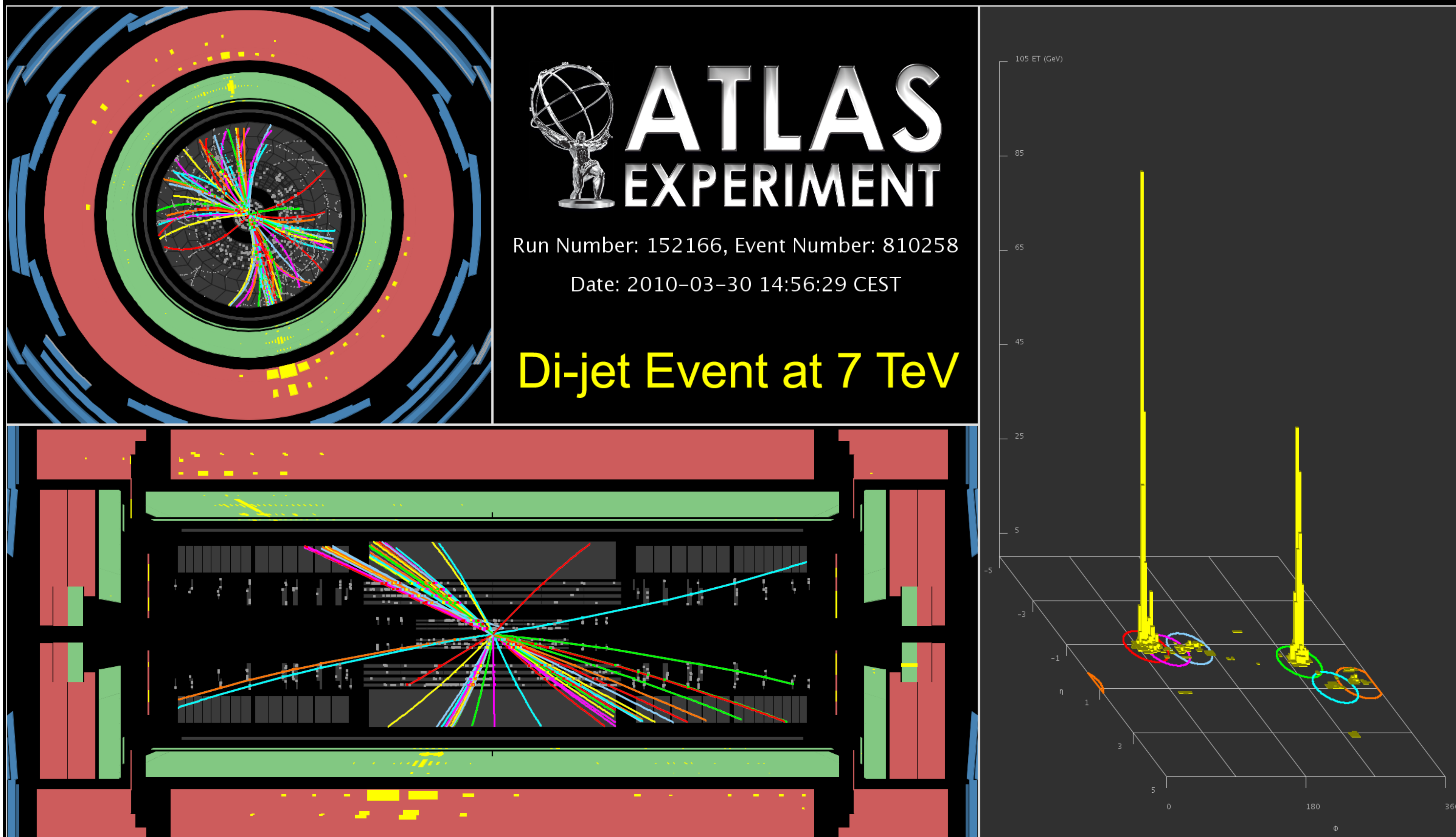


- Pixel detector measures energy loss dE/dx
  - Separates π,K,p
- Will also separate quasi-stable heavy charged particles (e.g. stau, …)
  - Interesting for new physics

- dE/dx selection used to enhance kaons
  - Clear $\Phi \rightarrow K^+K^-$ signal

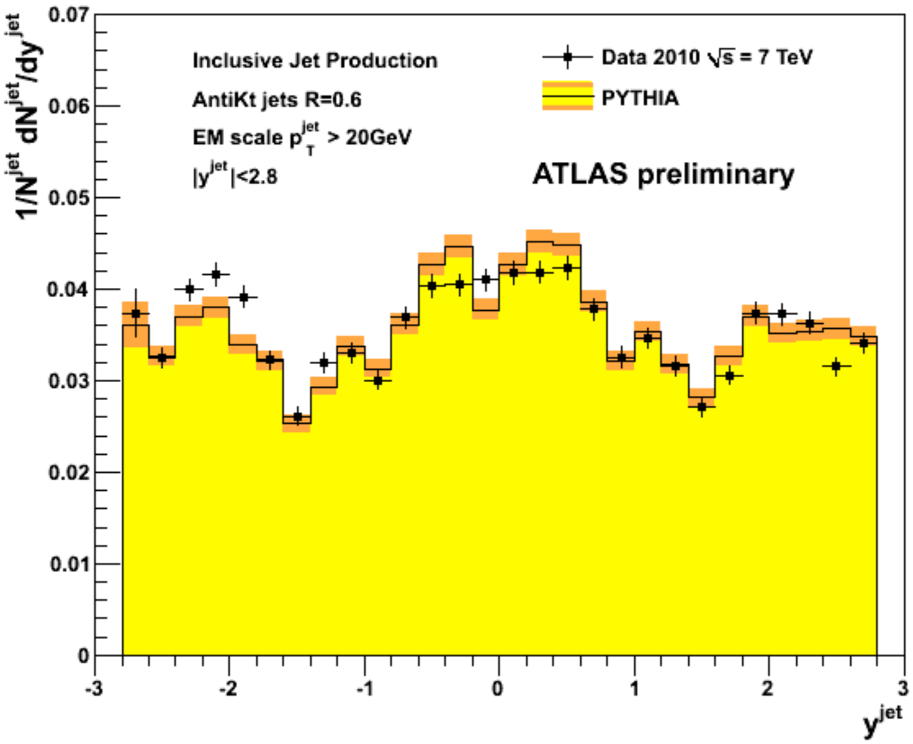


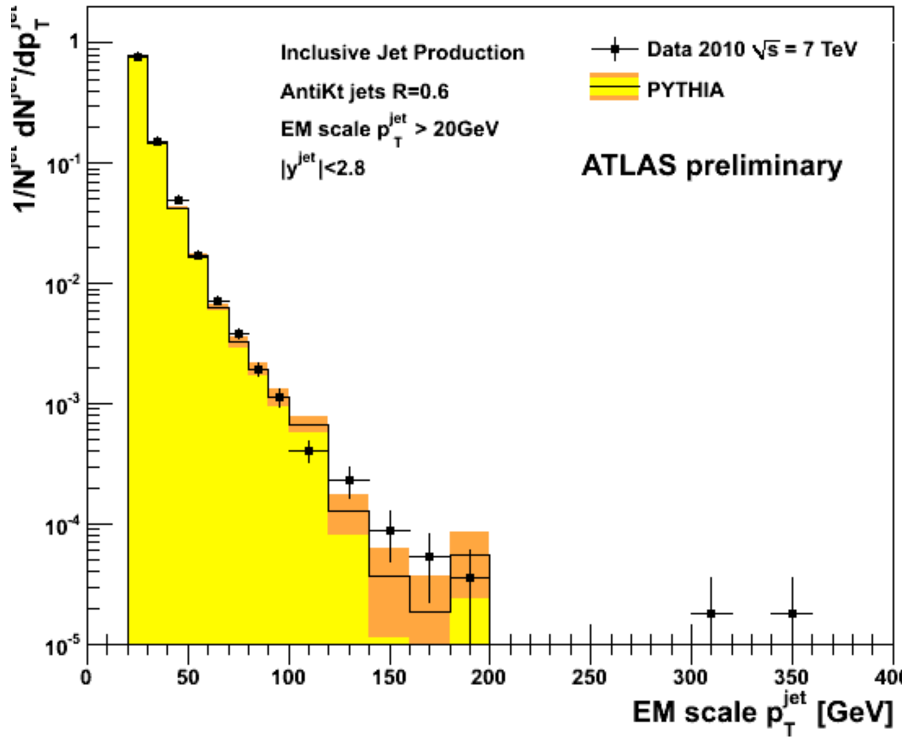
Jets



Raw measured jet energy: 300 GeV

Jets

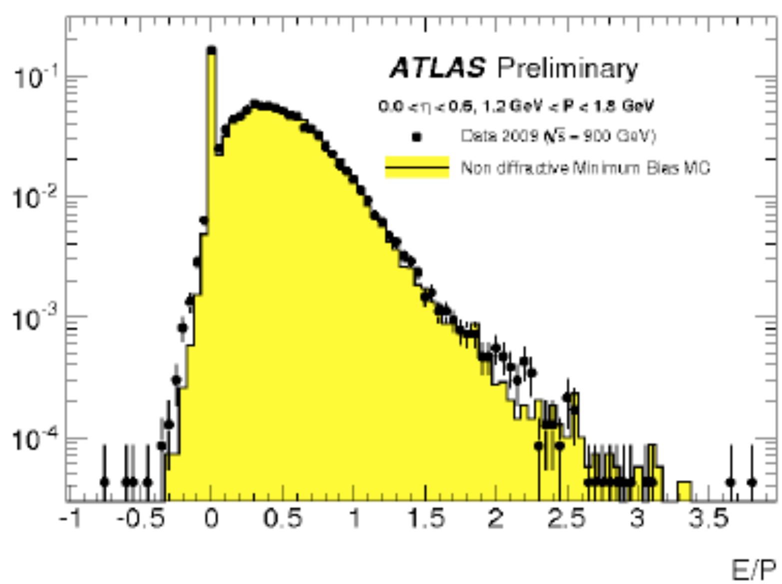


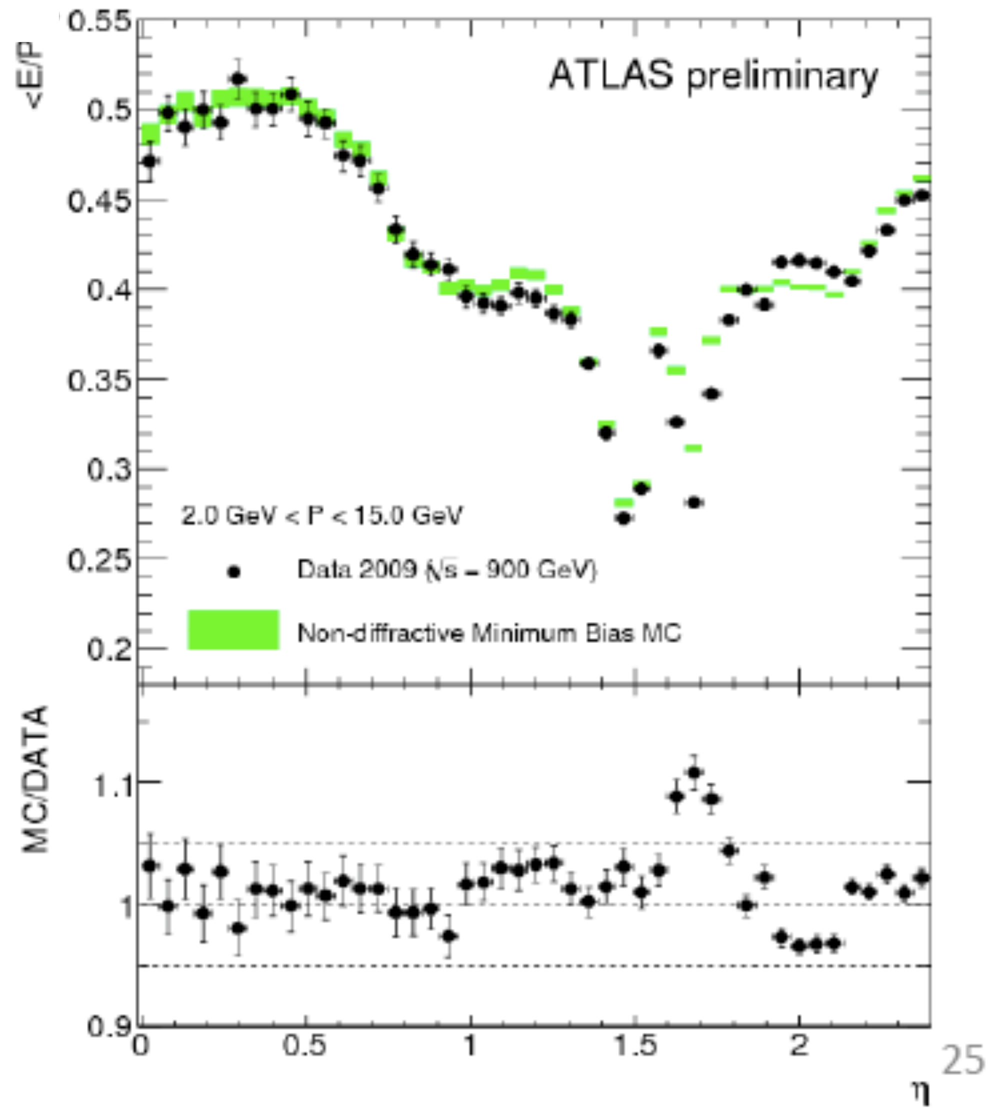


- Jet rapidity and p_T spectra agree well with Pythia simulation

yjet

Calorimeter Response

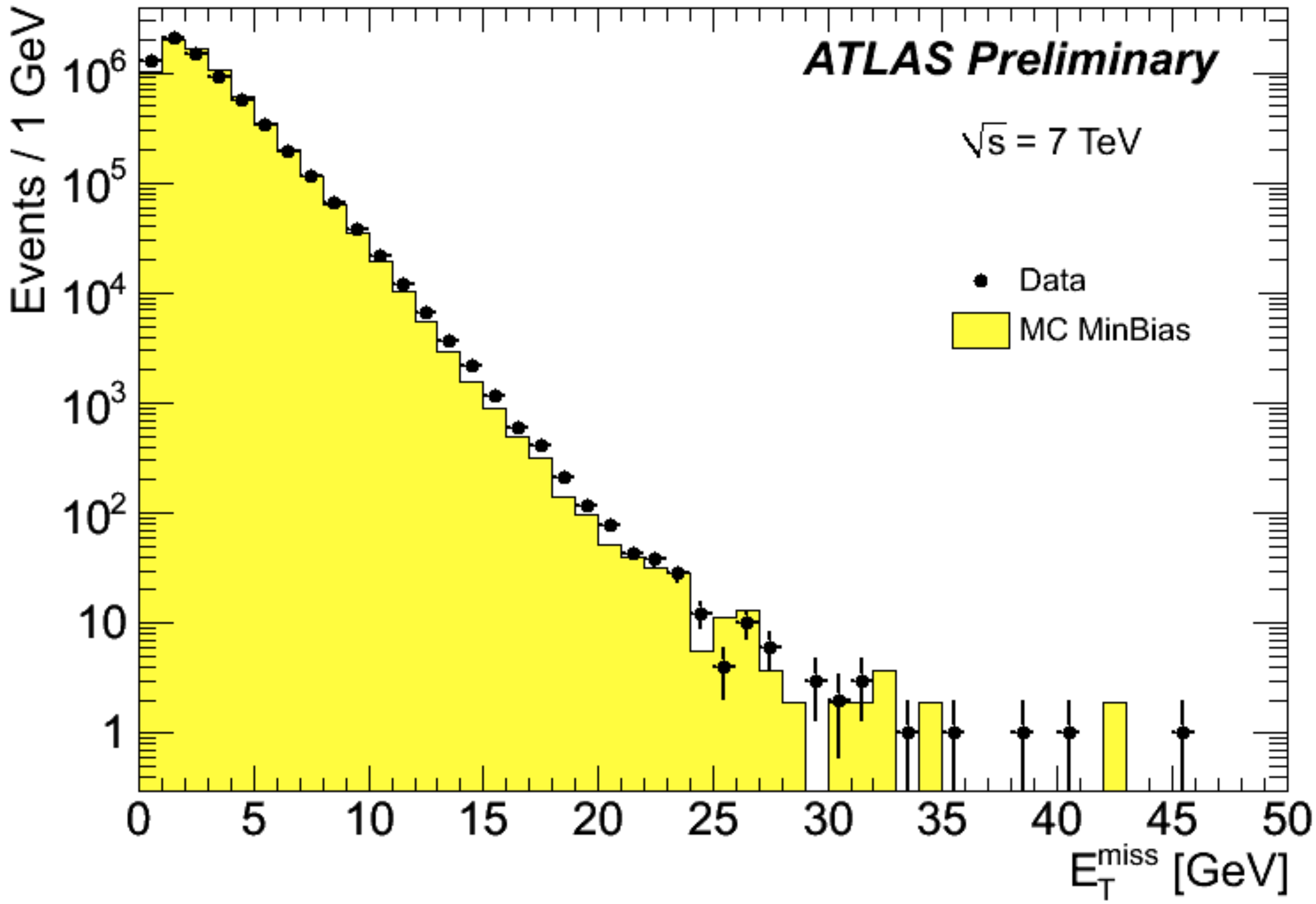




- Calorimeter energy in R=0.2 cone around track / track p
- Measures response of calorimeter to charged pions
  - Critical for jet calibration

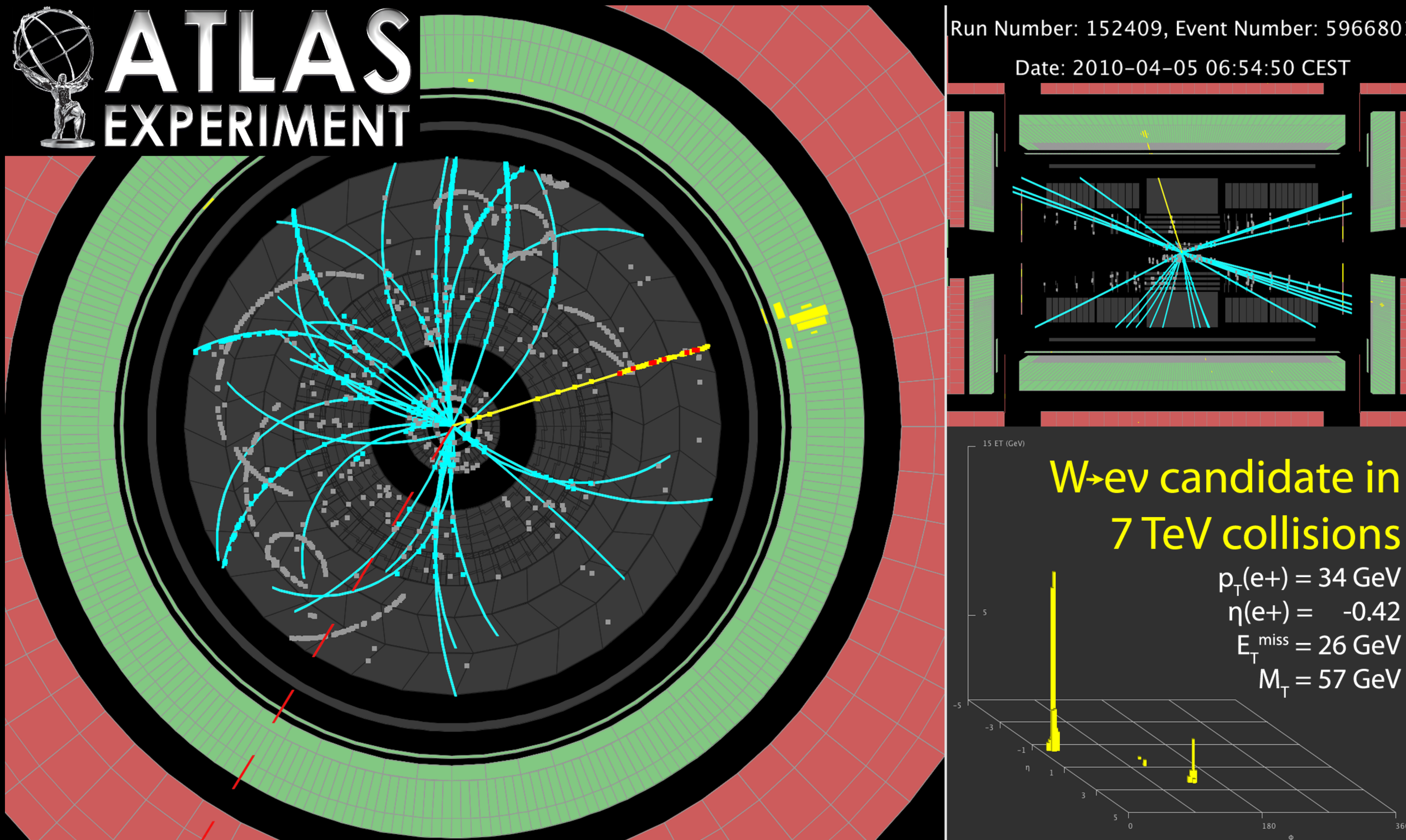
- Data generally very well described by MC

Missing E_T

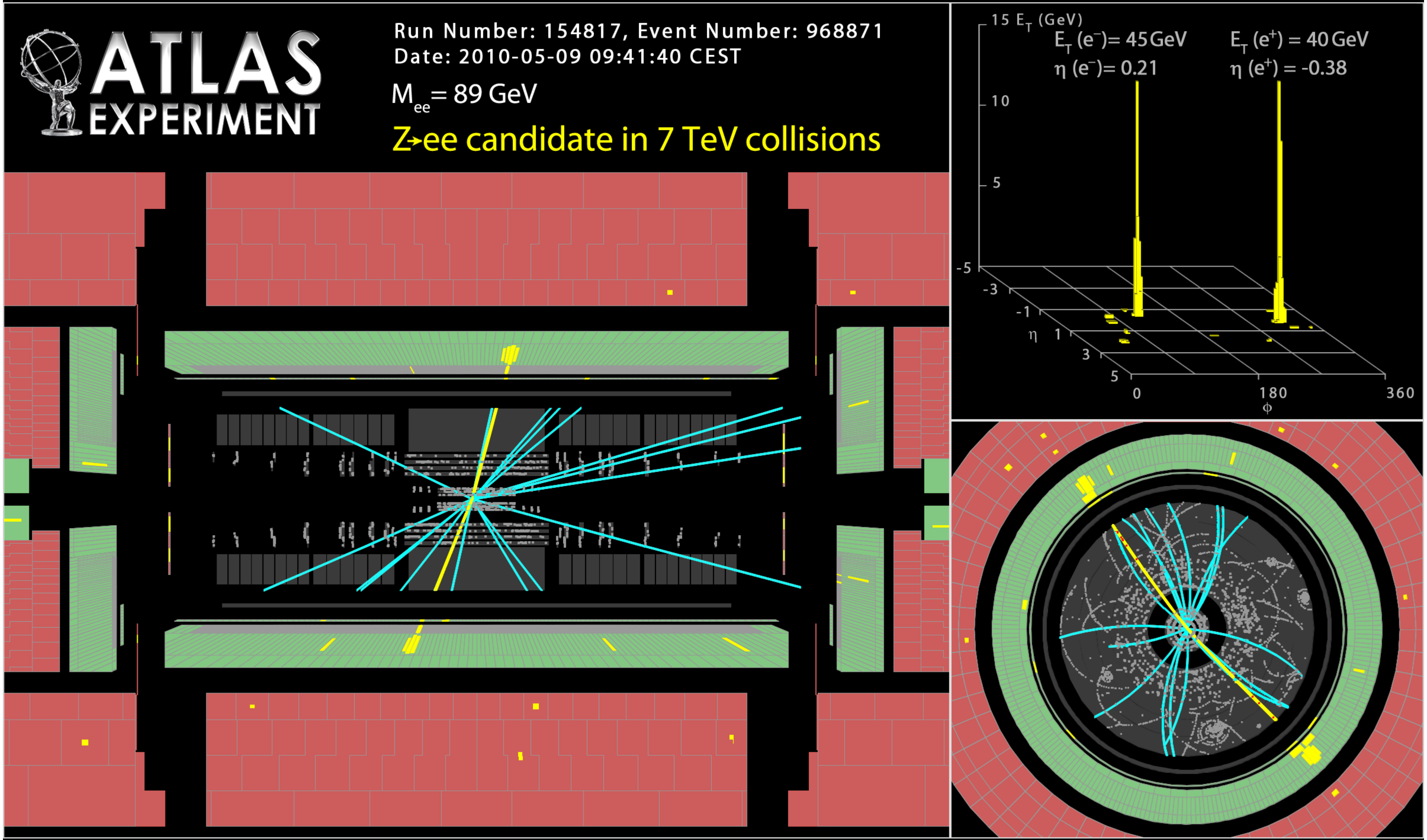


- Excellent agreement between data and MC
  – E.g. noise problems would lead to hard tail

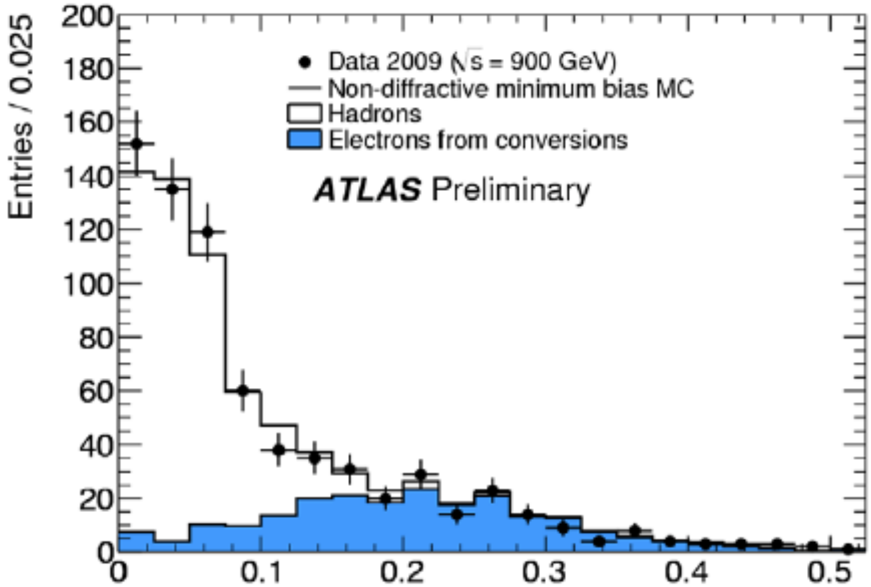
$W \rightarrow e\nu_e$



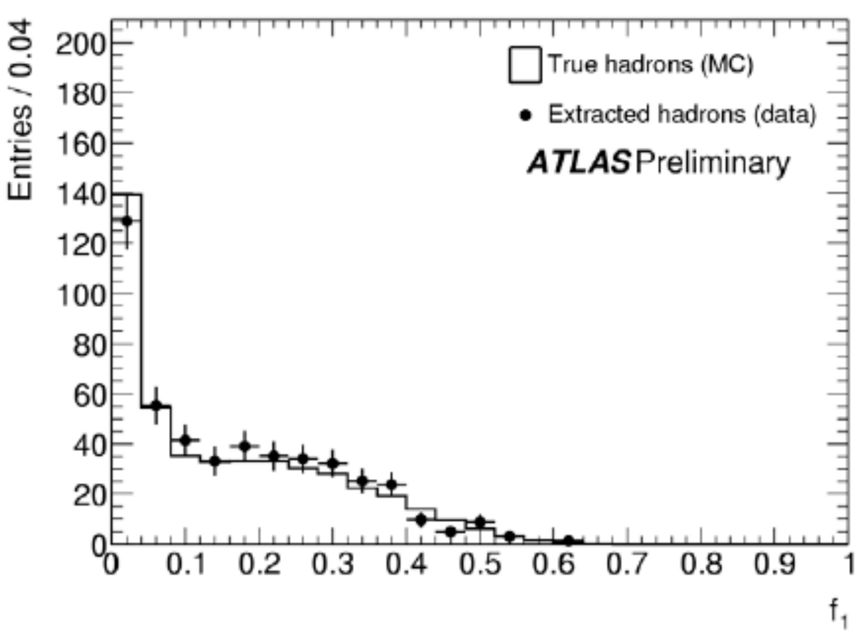
$Z \rightarrow e^+e^-$

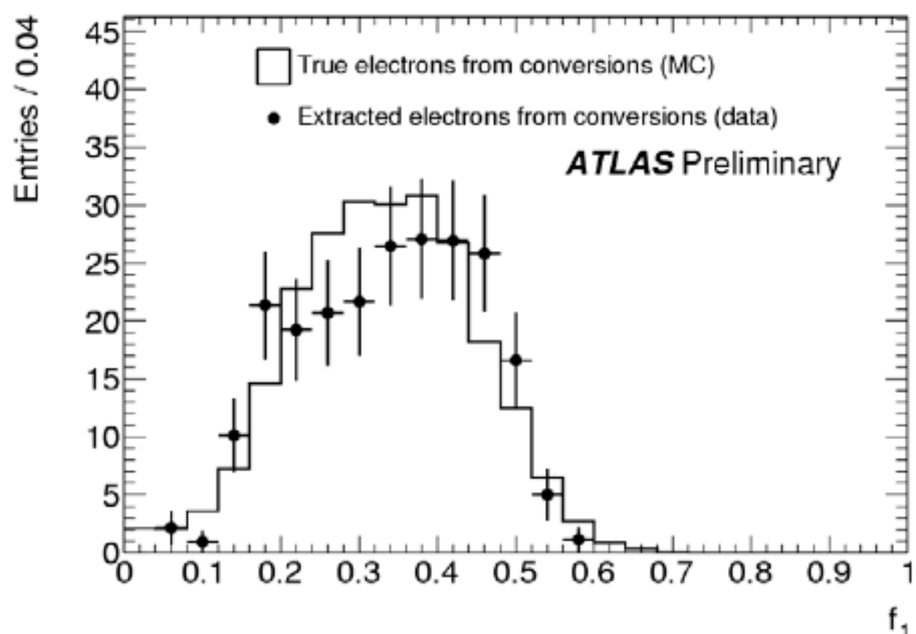


Low p_T Electrons

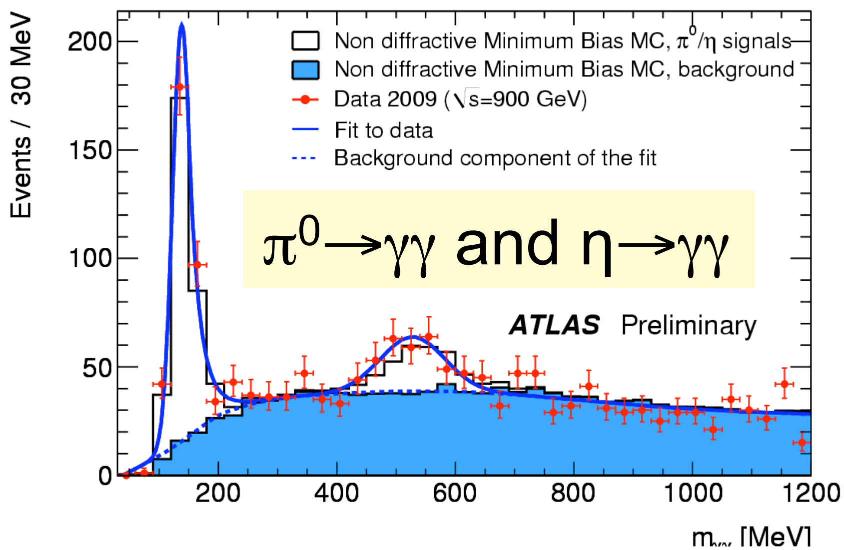


- Low p_T electrons mostly from conversions and fakes
  - TRT provides e/π separation
  - use TRT to enhance e sample
- Studies of many key electron identification variables
  - Data agree well with MC

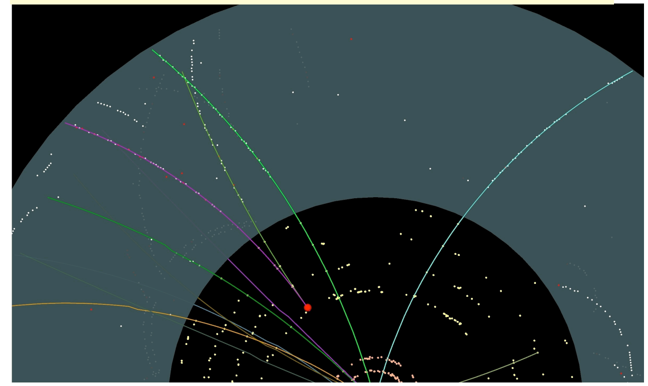


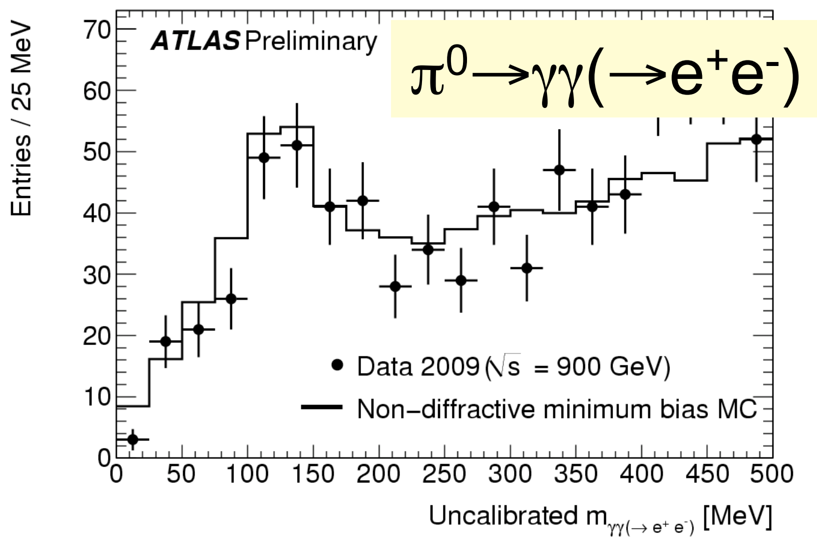


Photons and Conversions in 2009

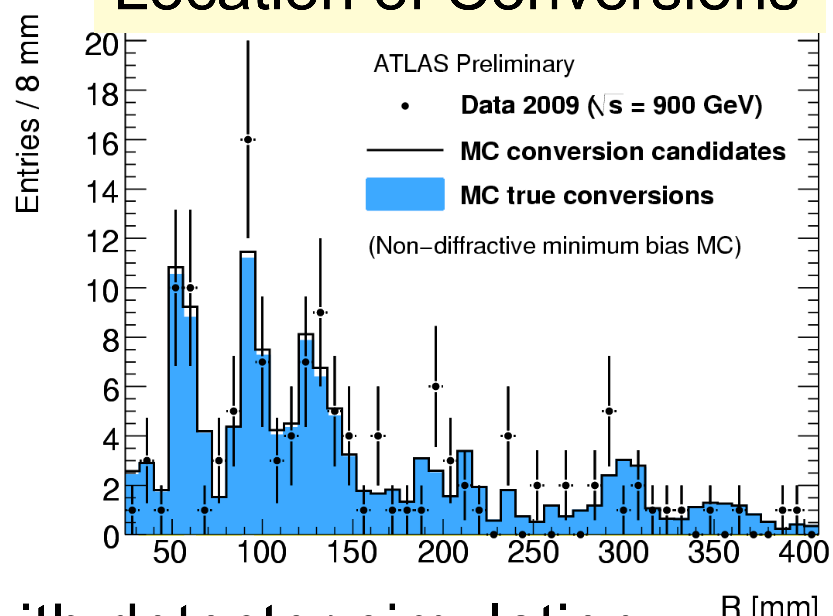


Conversion: $\gamma \rightarrow e^+e^-$



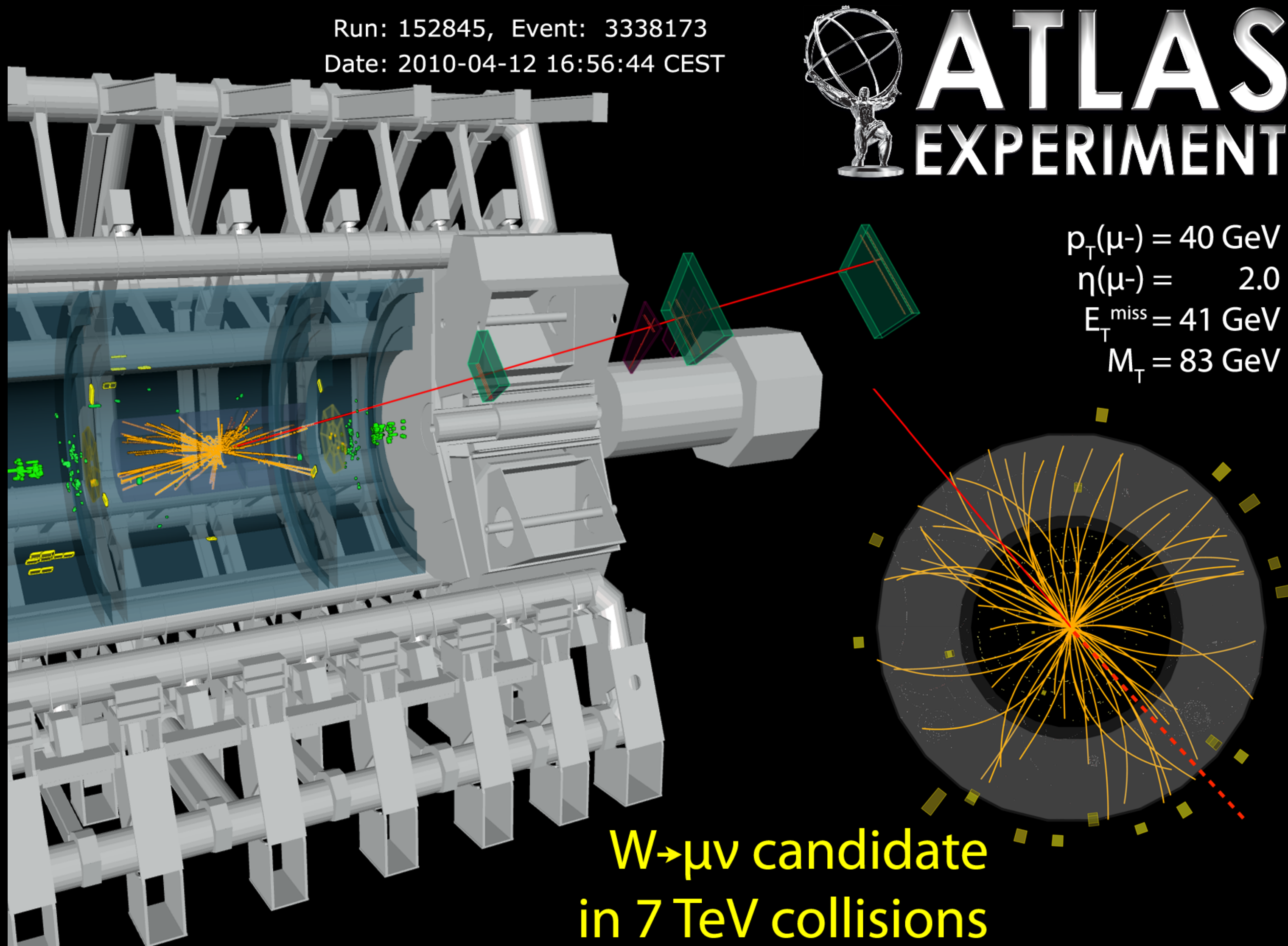


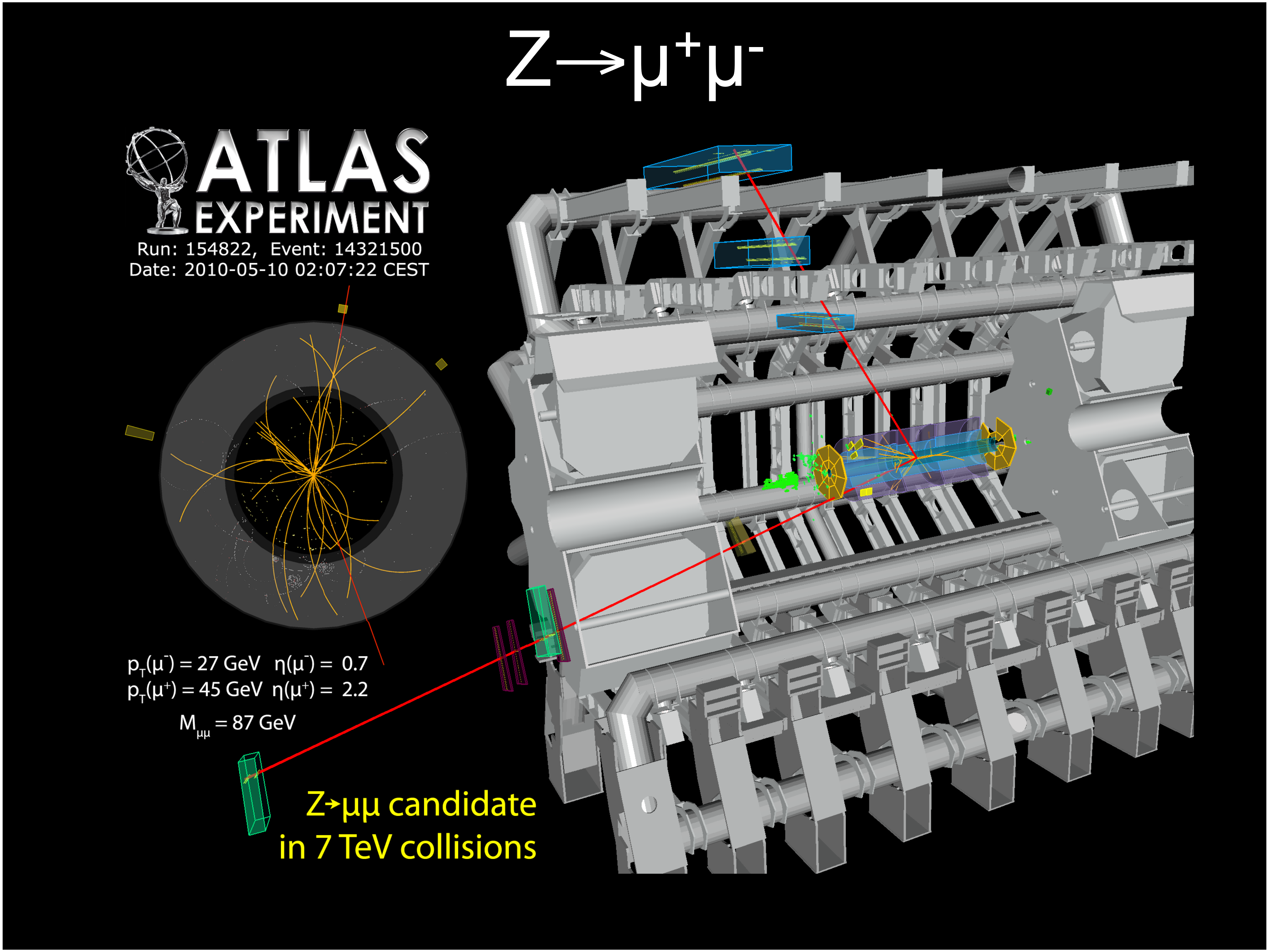
Location of Conversions



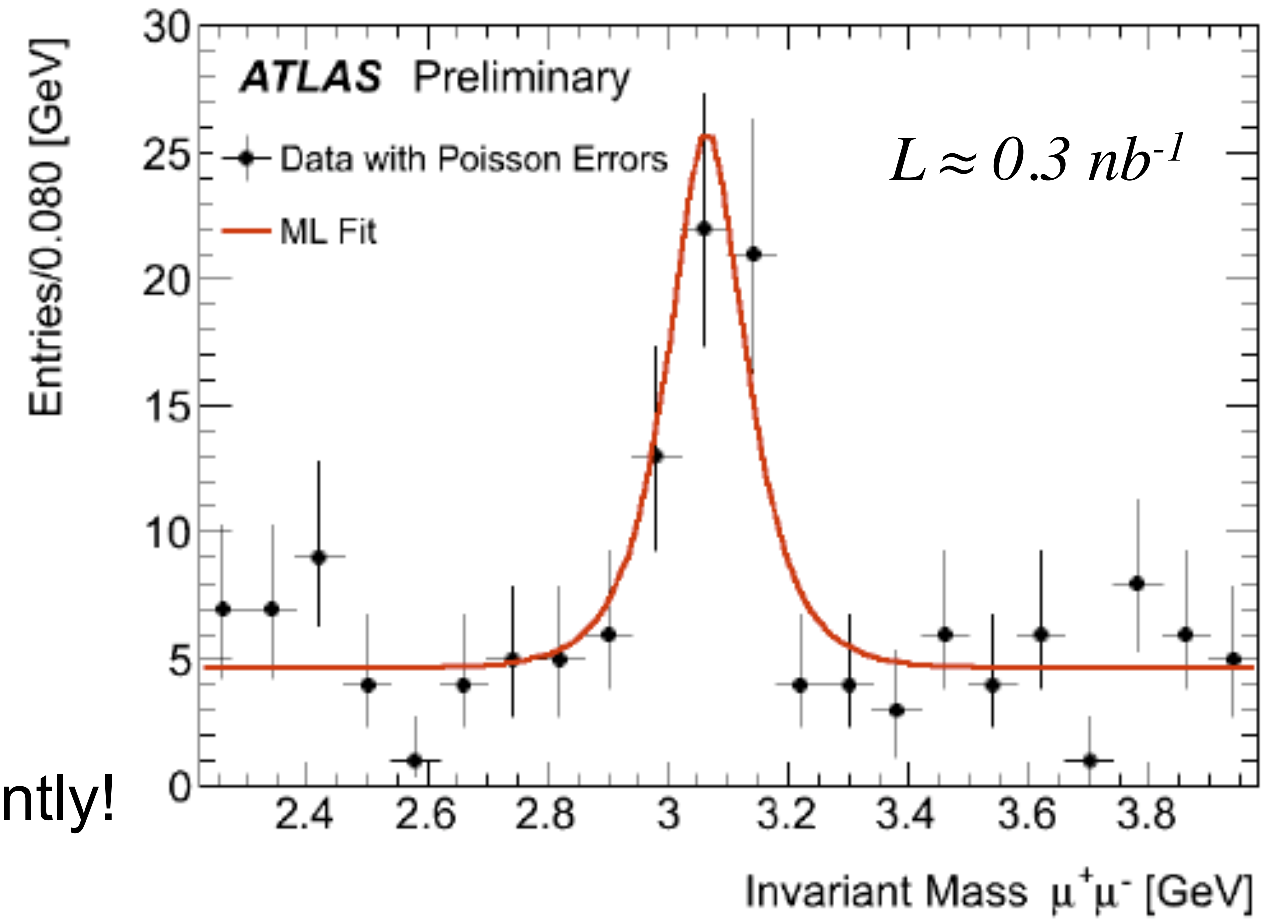
- Very good agreement of data with detector simulation

$W \longrightarrow \mu\nu_\mu$



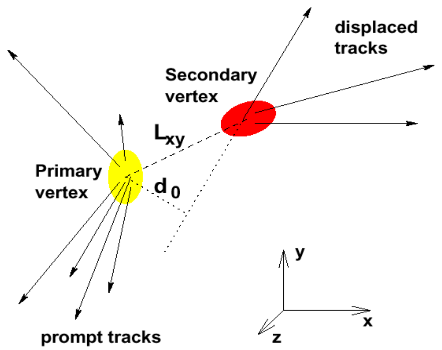

Z→μ⁺μ⁻
ATLAS EXPERIMENT
Run: 154822, Event: 14321500
Date: 2010-05-10 02:07:22 CEST
$p_T(\mu^-) = 27$ GeV $\eta(\mu^-) = 0.7$
$p_T(\mu^+) = 45$ GeV $\eta(\mu^+) = 2.2$
$M_{\mu\mu} = 87$ GeV
Z→μμ candidate
in 7 TeV collisions

Dimuon Mass Spectrum

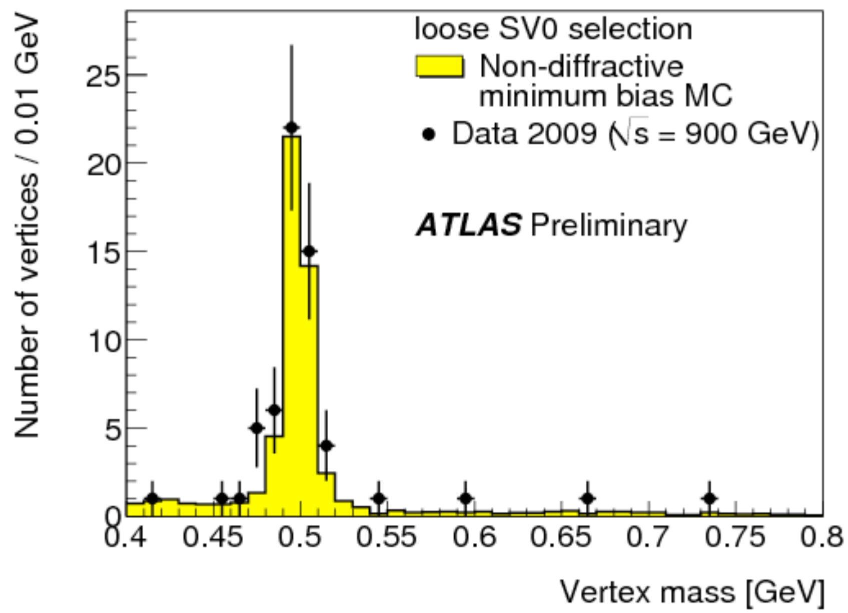


- J/ψ appeared recently!
  - $N_{event} = 49 \pm 12$
  - Mass = 3.08 ± 0.02 GeV/c^2
- Will now provide excellent calibration sample

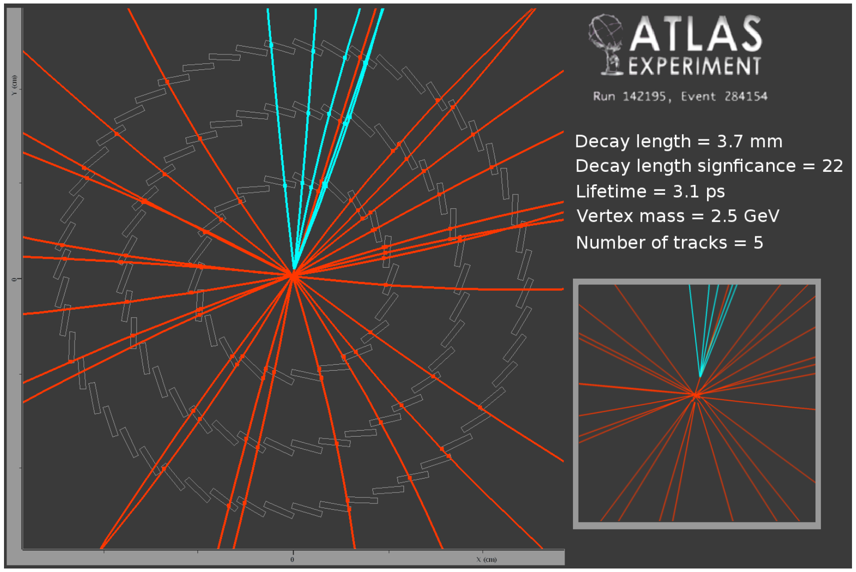
First B-tags in ATLAS



Decay distance of b:
$c\tau \approx 0.5$ mm



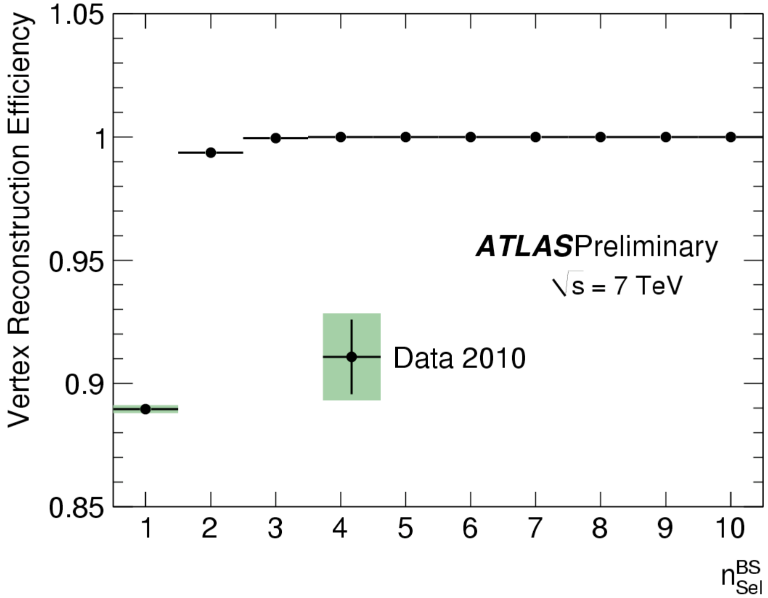
- Vertex tags in 900 GeV data
  - Remove vetoes against K^0_s, Λ^0, material interactions
  - Good agreement between data and MC
- May have seen first b-jet in ATLAS

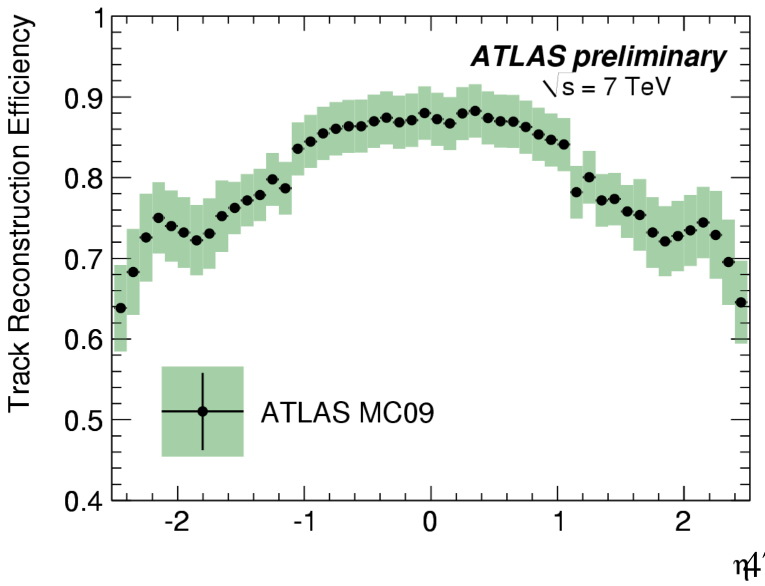


First Physics Results

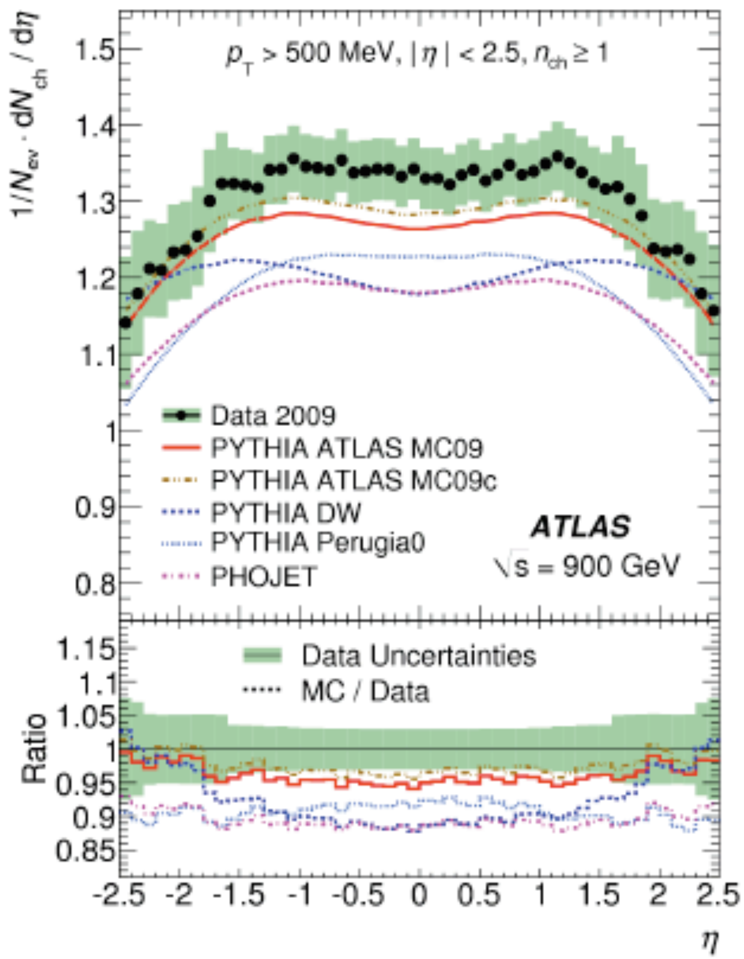
Charged Particle Multiplicities

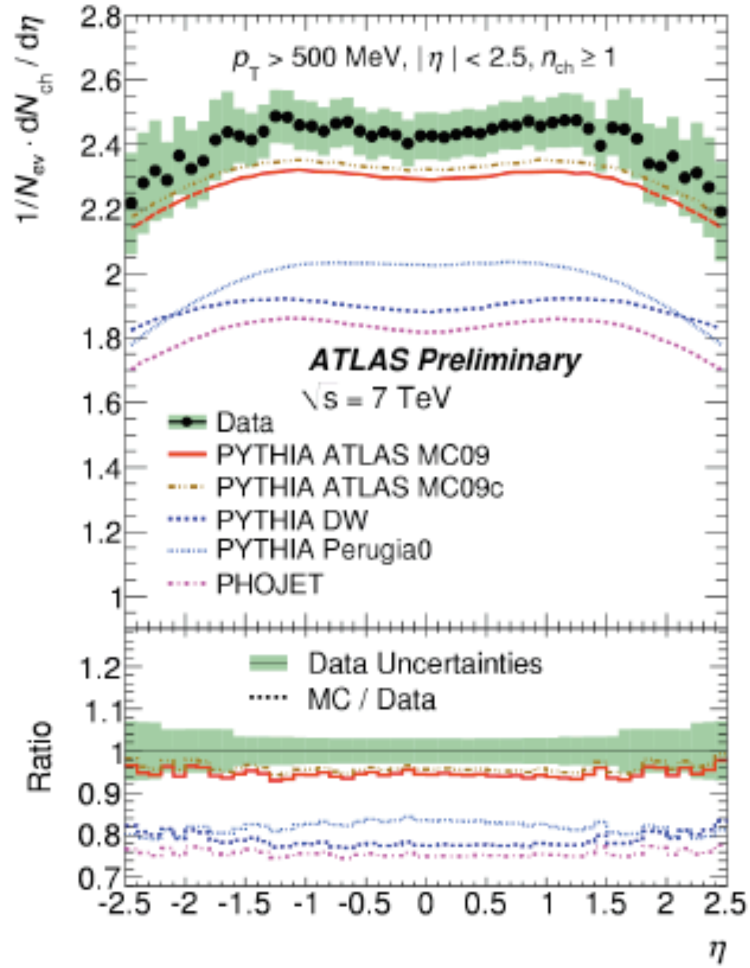
- Measurement useful for
  - Tuning MC models
  - Measuring luminosity
  - Understanding soft QCD
- Phase space
  - p_T>0.5 GeV
  - $|\eta|$<2.5
  - $N_{charged}$≥1
- Corrected for trigger, tracking and vertex efficiencies





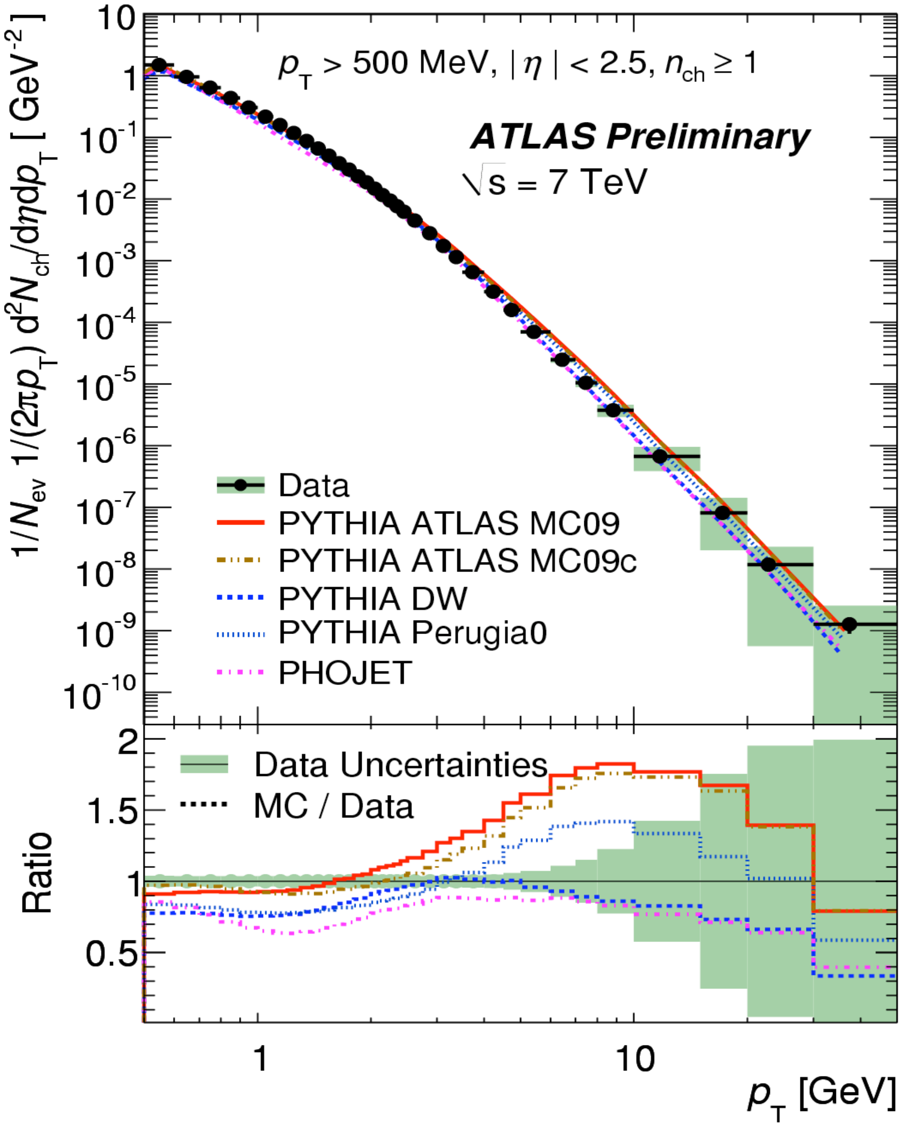
dN/dη

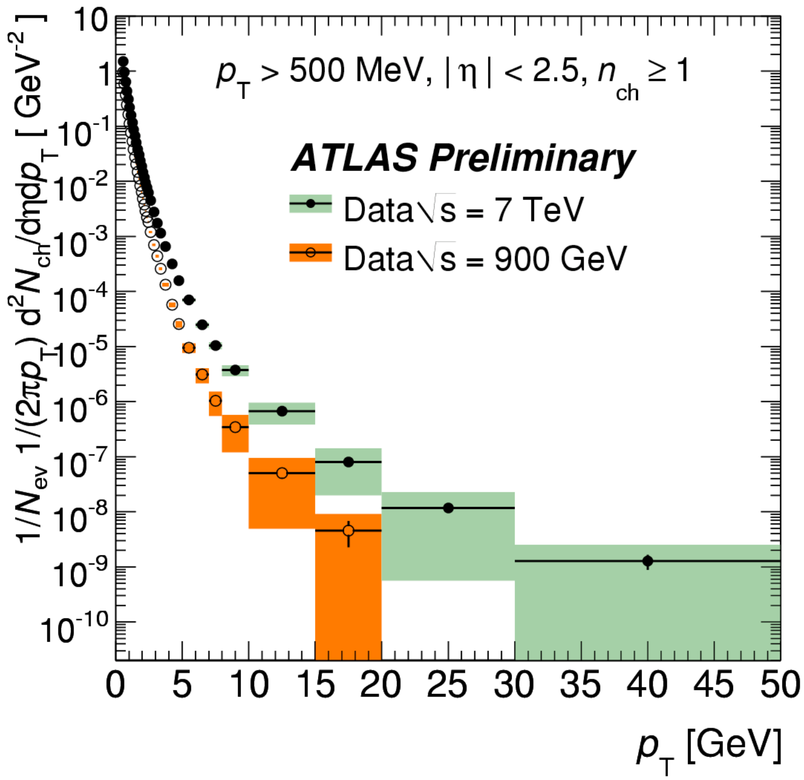




- Current MC tunes underestimate data
- Increase about factor 1.8 from 0.9 to 7 TeV

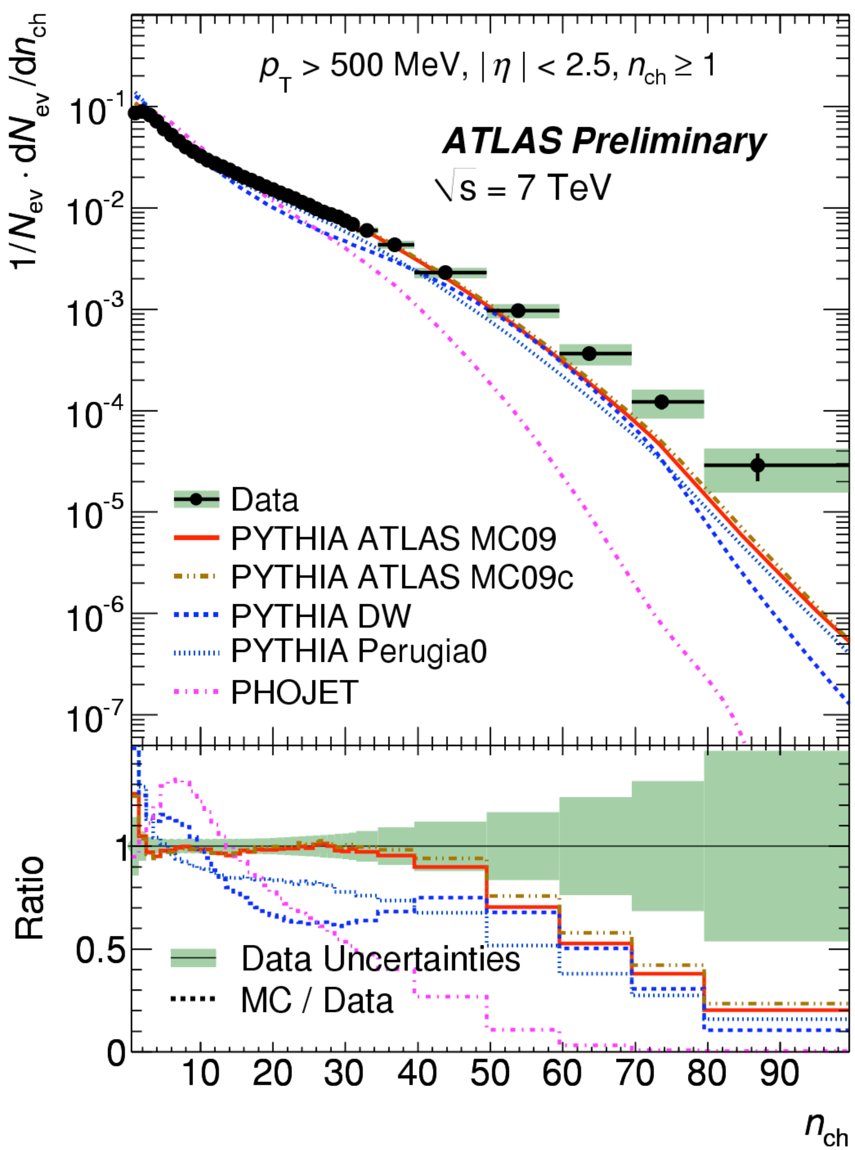
p_T Spectrum

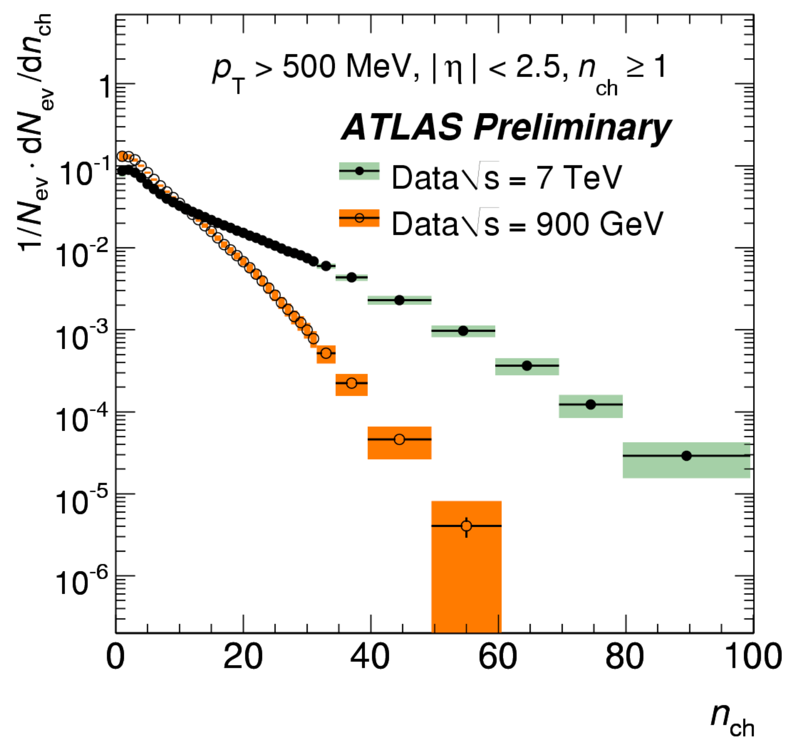




- Clear hardening of p_T spectrum observed
- MC models disagree by 20-80%

Number of Charged Particles

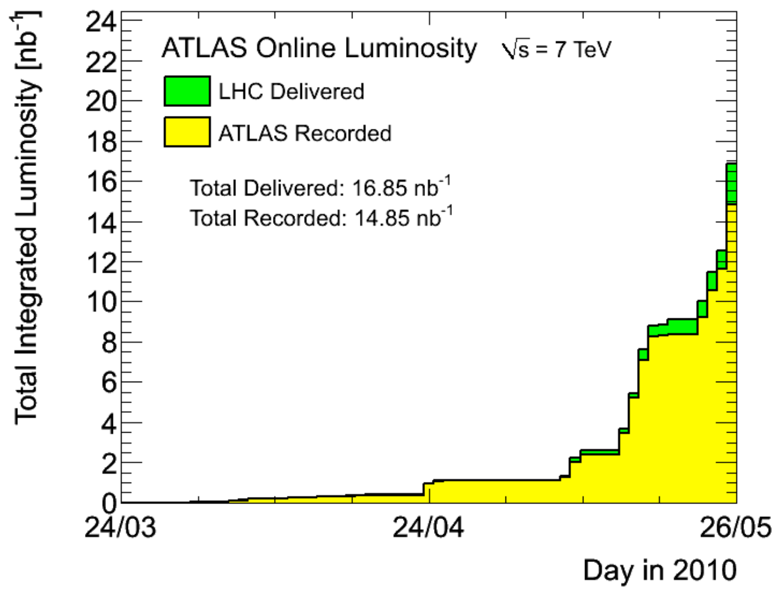


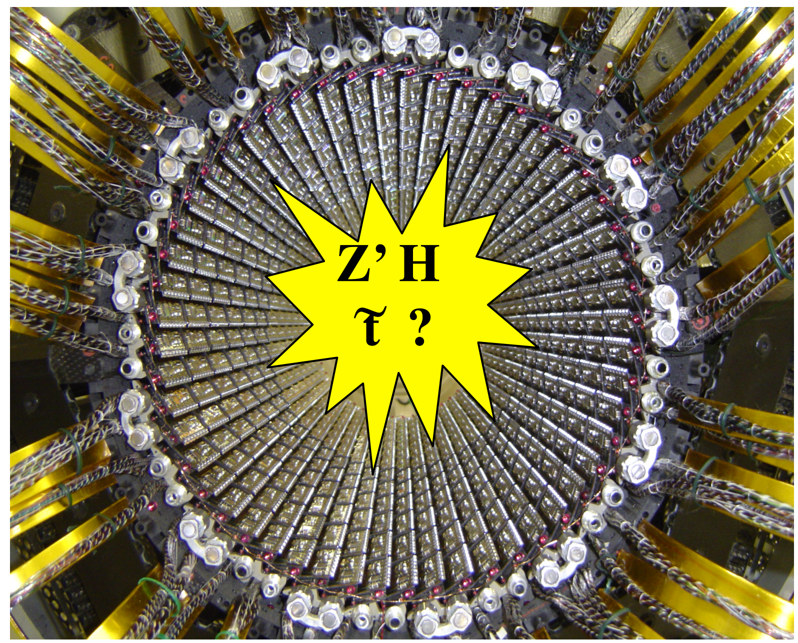


- Multiplicity increased at 7 TeV
- MC models disagree by 20-80%
  - In particular they all undershoot at high $N_{charged}$

Conclusions and Outlook

- **The LHC era has started**
  - Detectors are operating well
  - LHC performance remarkable *and* improving week by week
    - On track for 1 fb^{-1} in 2011
- **ATLAS detector pretty well understood already**
  - Good agreement between data and simulation for
    - Tracking, Jets and Missing E_T, lepton/γ identification
  - First J/ψ's, W's and Z's seen
- **If Nature is kind LHC experiments can find something in 2011**





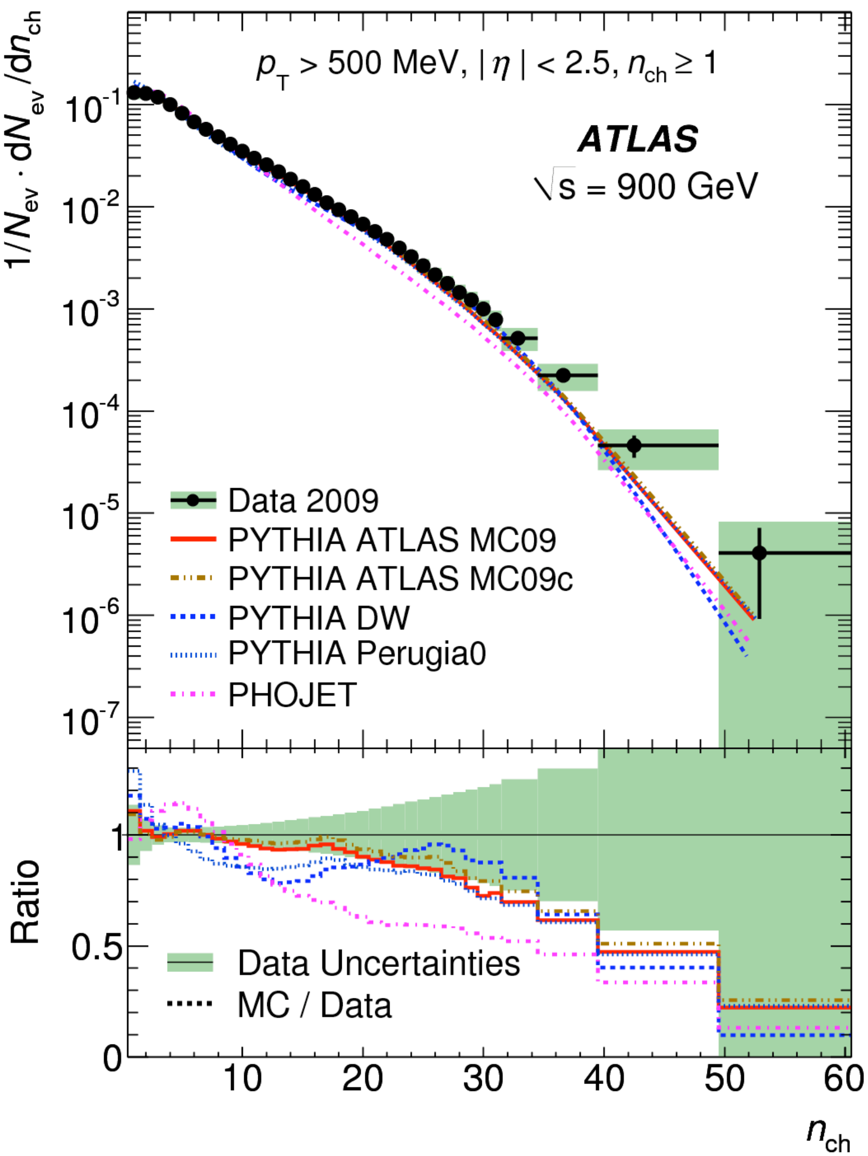
How to get to 1 fb^{-1}?

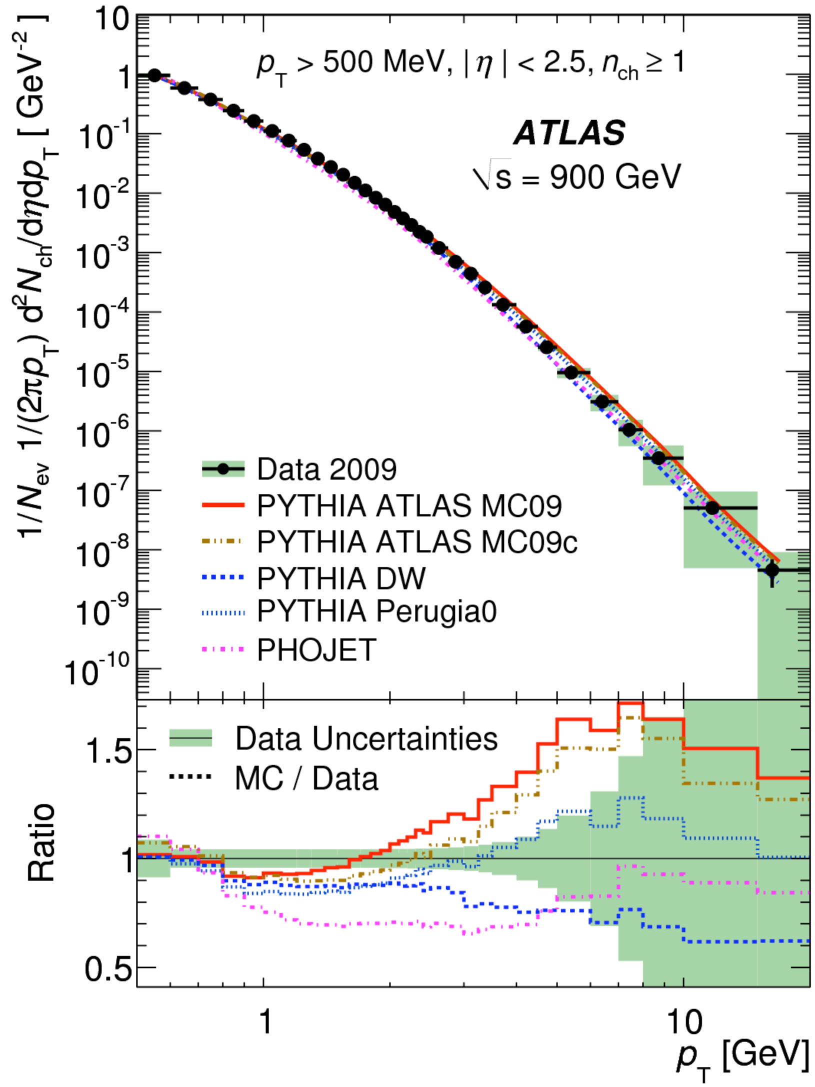
	LHC (now)	LHC (2011*)	LHC (design)
√s [TeV]	7	7	14
# of colliding bunches	≤ 3	≈ 700	2808
Protons/bunch [10^{10}]	2	11.5	11.5
Energy stored (MJ)	<0.1	≈ 35	362
Peak Luminosity [$cm^{-2}s^{-1}$]	7×10^{28}	$1\text{-}2 \times 10^{32}$	10^{34}
Integrated Luminosity	10 nb^{-1}	1 fb^{-1}	10-100 fb^{-1} /yr

(* plan constantly adjusted in reaction to what is learned)

- In following weeks
  - **Increase current per bunch from 2×10^{10} to 11.5×10^{10}**
    - Gain factor 25 in luminosity
    - But go back to β*=5m initially (loose factor 2.5 in luminosity)
  - **Increase number of bunches each week by factor ~2**
    - Gains factor 2 in luminosity each week

900 GeV Data


p_T > 500 MeV, $|\eta|$ < 2.5, $n_{ch} \geq 1$
ATLAS
$\sqrt{s}$ = 900 GeV
Data 2009
PYTHIA ATLAS MC09
PYTHIA ATLAS MC09c
PYTHIA DW
PYTHIA Perugia0
PHOJET
Data Uncertainties
MC / Data
$1/N_{ev} \cdot dN_{ev}/dn_{ch}$
Ratio
n_{ch}


p_T > 500 MeV, $|\eta|$ < 2.5, $n_{ch} \geq 1$
ATLAS
$\sqrt{s}$ = 900 GeV
Data 2009
PYTHIA ATLAS MC09
PYTHIA ATLAS MC09c
PYTHIA DW
PYTHIA Perugia0
PHOJET
Data Uncertainties
MC / Data
$1/N_{ev}\ 1/(2\pi p_T)\ d^2N_{ch}/d\eta dp_T$ [GeV^{-2}]
Ratio
p_T [GeV]